



Spatial Epidemiological Investigation of Sport and Leisure Injuries in Victoria, Australia

This thesis is submitted in total fulfilment of the requirements of the degree of Doctor of
Philosophy

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Himalaya Singh

Australian Centre for Research into Injury in Sport and its Prevention (ACRISP)

Centre for eResearch and Digital Innovation (CeRDI)

School of Health Sciences and Psychology, Faculty of Health

Federation University Australia

Abstract

Sport and leisure injuries are recognised as a public health issue in Australia. Despite the many health benefits associated with sport and leisure participation, there is a risk of sustaining injury during participation. To keep Australia active, there is a critical need to prevent injury occurrence.

Epidemiological investigations in sport and leisure injuries have been largely examined by grouping of sports, age groups, sex and level of play. In addition, intrinsic (person-level) factors have been considered, such as strength, flexibility or previous injury history. These factors may not be sufficient to identify injury burden or prevent an increase in injury incidences. In the broader injury literature (e.g., road traffic crashes or drowning), it is known that injuries often cluster within specific places (i.e., road intersections or bodies of water). These specific geographic locations may also relate to sport and leisure injuries (e.g., sports grounds or facilities). Similarly, population-level factors such as socio-economic status or cultural groups within an area could influence the types of sports and leisure activities people participate in and consequently, the injuries that occur.

A review presented in this PhD thesis revealed that there is very limited sport and leisure injury epidemiological information from a geographical perspective. To address this gap, and determine whether there is a spatial pattern in sport/leisure injuries, the aim of this PhD was to examine the geospatial distribution of sport/leisure injury hospitalisations and their association with a broad range of social and economic characteristics. This thesis uses spatial epidemiological methods to answer questions such as ‘Where do sports and leisure injuries occur?’ and ‘In whom do sports/leisure injuries occur?’ The main chapters present the results of the application of spatial epidemiological methods to describe the problem, to test hypotheses and to explore associations with possible explanatory variables. The findings showed a significant variation across metropolitan, regional and rural areas in the pattern and clustering of injuries when examining different sports, age groups and other variables such as education level.

A secondary aim of this thesis was to consider the dissemination of sport and injury epidemiological data. As emphasised in the literature, there is limited spatial epidemiological information available to decision-makers and key stakeholders. At best, descriptive maps

might be included in a report or research paper. However, these are static and limited to the results that the author chooses to present. Therefore, an important output from this PhD is a web-GIS application that has been specifically built to enable the exploratory analysis of sport/leisure injuries in Victoria.

Sport and leisure injury prevention strategies and policy development relies on information about where, when, to whom and how sport/leisure injuries occur. This thesis demonstrates that a spatial epidemiological approach is an important and novel way to address epidemiological questions from a geographical perspective.

Declaration

I, Himalaya Singh, declare that the PhD thesis entitled ‘Spatial Epidemiological Investigation of Sport and Leisure Injuries, Victoria, Australia’ contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma except where explicit reference is made in the text of the thesis. All the images included in this thesis were either created or adapted by me or commissioned by me. The thesis does not include material with copyright provisions or requiring copyright approvals.



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Himalaya Singh

March 2018

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Dedication

To my father

List of Publications and Awards

1.1 Full Articles

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1.2 Published Abstracts

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1.3 Conference Presentations

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1.4 Awards

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Glossary

ABS	Australian Bureau of Statistics
ACRISP	Australian Centre for Research into Injury in Sport and its Prevention
ANOVA	Analysis of Variance
ARIA+	Accessibility/Remoteness Index of Australia
ASC	Australian Sports Commission
ASGS	Australian Statistical Geography Standard
BYM	Besag, York and Mollié
CAR	Conditional Autoregressive Models
CeRDI	Centre for eResearch and Digital Innovation
CI	Confidence Interval
DBMS	Database Management System
DHHS	Department of Health and Human Services
EB	Empirical Bayes
ED	Emergency Department
ESRI	Economic and Social Research Institute
GIS	Geographic Information Systems
GPS	Global Positioning System
GPs	General Practitioners
GLM	Generalised Linear Model
GWR	Geographically Weighted Regression
HREC	Human Ethics Research Committee
ICD-10-AM	International Classification of Diseases Australian Modification
IRSAD	Index of Relative Socio-economic Advantage and Disadvantage
JSON	JavaScript Object Notation
KDE	Kernel Density Estimation
LGA	Local Government Area
LISA	Local Indicator of Spatial Autocorrelation
MAUP	Modifiable Area Unit Problem
MPHS	Multi-Purpose Household Survey
NCCH	National Centre for Classification in Health
NHMRC	National Health and Medical Research Council

NnH	Nearest neighbour Hierarchical
NNI	Nearest Neighbour Index
NSW	New South Wales
OLS	Ordinary Least Square
POA	Postal Areas
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
RA	Remoteness Areas
REST	Representational State Transfer
SEIFA	Socio-Economic Indexes For Areas
SES	Socio-Economic Status
VAED	Victorian Admitted Episodes Dataset
VASLI	Victorian Atlas of Sport and Leisure Injuries
VIF	Variance Inflation Factor
VISU	Victorian Injury Surveillance Unit
WHO	World Health Organization

Chapter 1: Introduction

1.1 Sports and Leisure Injuries

The problem of sport and leisure (hereafter referred to as sport/leisure) injuries is recognised as a population-level public health issue in Australia (Andrew, Gabbe, Wolfe & Cameron, 2012; Finch, 2011; Finch, Mitchell & Boufous, 2011). There has been increasing recognition that sports/leisure participation can play a prominent role in improving health-related quality of life (Macera, Hootman & Sniezek, 2003; Reiner, Niermann, Jekauc & Woll, 2013; Warburton, Nicol & Bredin, 2006). Although there are significant health, psychological and social benefits from sport/leisure participation (Eime, Young, Harvey, Charity & Payne, 2013; Reiner et al., 2013), it is also associated with a risk of injury (Finch & Cassell, 2006; Finch & Boufous, 2009; Mitchell, Finch & Boufous, 2010). In general, sport/leisure injury is any form of physical damage sustained by a participant while participating in sport/leisure activities (Timpka et al., 2014). A sport/leisure injury can be serious enough to require immediate medical attention or less serious in that it only affects daily activities or further participation (Finch & Cassell, 2006; Timpka et al., 2014).

A study conducted in Victoria, Australia estimated that approximately five per cent of active sport/leisure participants sustained an injury in a two-week period (Finch & Cassell, 2006). Other studies have reported that the annual rate of hospital-treated sport/leisure injuries has increased by 24 per cent for adults (15+ years) and 29 per cent for children (<15 years) in 2004–2010 in Victoria (Finch, Kemp & Clapperton, 2015; Finch, Wong Shee & Clapperton, 2014). In 2004, the cost of sport/leisure-related injuries was estimated at AUD 1.8 billion per annum in Australia (Gabbe, Finch, Cameron & Williamson, 2005). Epidemiological enquiries from around the world have demonstrated that sport/leisure injuries are a significant public health burden to the individual and society (Conn, Annest & Gilchrist, 2003; Finch & Cassell, 2006; Schneider, Seither, Tönges & Schmitt, 2006). Therefore, a preventive approach should be implemented to reduce sport/leisure injuries at the population level.

1.1.1 Theoretical frameworks for sport/leisure injury prevention

A four-step framework (see Figure 1.1) developed by van Mechelen is often applied to public health issues to guide prevention strategies at the population level (van Mechelen, Hlobil &

Kemper, 1992). The first stage of this framework is focused on the systematic collection of quality data to define the problem. Once the problem is identified, the second stage identifies protective factors and risk factors that need be considered in the development of injury prevention interventions. Every intervention is evaluated for its cost and impact effectiveness before its implementation within the wider population. The framework is an iterative process over time. Every implemented strategy is evaluated and amended if necessary to further improve the process and increase the effectiveness of prevention strategies. The longitudinal change is assessed through surveillance after the prevention strategies are implemented. This PhD thesis is focused on Stages 1 and 2 of the framework. Stage 1 identifies the magnitude, scope and characteristics of sport/leisure injuries from a geographical perspective. Stage 2 demonstrates how external risk factors can be investigated using the geospatial analysis approach.

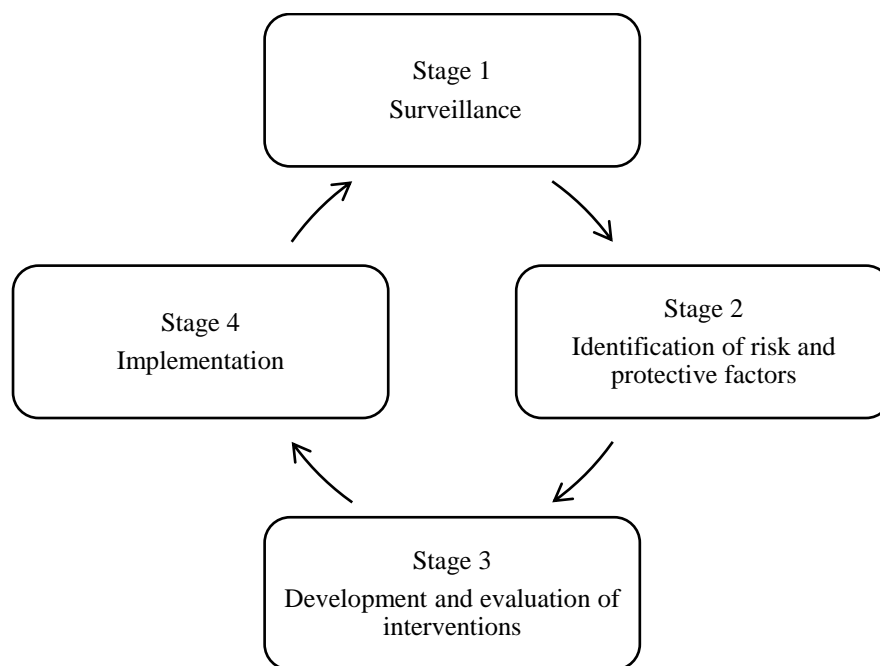


Figure 1.1: Sequence of prevention model, Adapted from (van Mechelen, Hlobil & Kemper, 1992)

1.1.2 Extent of the sport/leisure injury problem

According to the sequence of prevention model, Stage 1 is focused on surveillance of sport/leisure injury data with the aim of defining the extent of the sport/leisure injury problem. It is important to understand that the extent of the sport/leisure injury problem is largely dependent on the source of the data (Cassell, Finch & Stathakis, 2003; Finch, 2011).

The extent of the sport/leisure injury problem is mostly defined using routinely collected (generally from hospital settings) injury data (Cassell et al., 2003; Conn, Annest, Gilchrist & Ryan, 2004; Finch et al., 2015; Gabbe et al., 2005). In some cases, the sports injury problem is also defined using data collected through other techniques, such as surveys (Ekegren et al., 2015; Fortington, Donaldson & Finch, 2016) or observations (Fortington et al., 2016) of a defined population. The disadvantage of these approaches is that the data are limited to smaller populations because the studies tend to be focused on injuries in a specific sport. However, data that is obtained using the study designs described above are advantageous to, address highly specific research questions. Further, these study designs enable the capture of different types of injuries, including minor injuries that do not require treatment in a hospital setting. For example, a survey conducted in New South Wales (NSW) demonstrated that 30.9 per cent of respondents involved in organised sports activities had been injured during participation (Mitchell et al., 2010). In this study, the authors reported only 8.9 per cent of the respondents were treated in a hospital setting (Mitchell et al., 2010).

Although only a small proportion of all sports injuries are likely to be treated in hospital settings, this data is highly useful to provide an overview of sport/leisure injuries at the population level. The information includes the extent of the sport/leisure injury problem by demographic and injury characteristics. Further, sports injury data from hospital settings enables a comparison of injuries over a larger population than can other study designs. This means that meaningful comparisons of injuries that occur in different geographical areas and populations can be made. A study that investigated sports injury hospitalisations in Victoria showed that hospitalised sports injuries accounted for more cases than workplace injuries (Andrew et al., 2012). Other studies of routine hospital data have shown that sport/leisure activities are the major cause of emergency department (ED) presentations for children (Finch, Valuri & Ozanne-Smith, 1998; Finch et al., 2014). Notwithstanding the various advantages and disadvantages described above, it is important to keep in mind that measurement of the extent of sports injury problem will vary based on the study design and source of the data.

The sport/leisure injuries treated in hospital settings have been most commonly described using specific variable such as sex, age groups, and specific activity (Cassell et al., 2003; Conn et al., 2004; King, Hume, Milburn & Gianotti, 2009; Kreisfeld, Harrison & Pointer, 2014; Mummery, Schofield & Spence, 2002; Schmikli, Backx, Kemler & van Mechelen,

2009). For example, the problem can be identified by sex (e.g., males have been shown to have a greater risk of sport/leisure injury compared to females (Cassell, Kerr & Clapperton, 2012; Kreisfeld et al., 2014)) or by age (e.g., the frequency of sport/leisure injuries is higher in 15–39 year olds than other age groups (Finch & Cassell, 2006)). Injuries can also be described by sport. For example, in Australian Football, field hockey, basketball and netball, participants aged 26–30 years were at a 55 per cent greater risk of injury than participants aged below 18 years (Stevenson, Hamer, Finch, Elliot & Kresnow, 2000). A study from the Netherlands identified target age groups based on different sports. For example, the target population for soccer injuries is males aged 4–54 years and females aged 4–17 years, while the target population for skiing/snowboarding injuries is males aged 4–17 years and females aged 18–34 years (Schmikli et al., 2009). There are many examples of research that explores the sport/leisure injury problem by demographic variables such as sex and age. However, there is limited information available on the sport/leisure injury problem in the context of other variables, such as those representing a geographical context. Thus, identifying novel methods to describe the extent of sport/leisure injury problem in a geographical context is important and addresses a major knowledge gap.

In a geographical context, studies from NSW have identified a significant association between sport/leisure injury hospitalisations and geographic location, categorised by the remoteness index of Australia (Finch & Boufous, 2009; Lam, 2005). The findings suggested rural and remote areas have significantly higher rates of sports-related injury hospitalisations compared to metropolitan areas (Finch & Boufous, 2009), with a higher risk among children and adolescents (Lam, 2005). Information about the geographic distribution of sports/leisure injuries potentially has powerful policy implications for targeting injury prevention efforts and resource allocation (Chong & Mitchell, 2009; Colantonio et al., 2011), yet little information is currently available in this context.

1.1.3 Aetiology and mechanisms of sport and leisure injury

The investigation into the aetiology and mechanism of sport/leisure injury is part of Stage 2 of the Sequence of prevention model. The majority of sports injury epidemiological studies have explored immediate or internal factors for injury (i.e., factors within the individual's control such as equipment use and training-related behaviour) (McBain et al., 2012). However, in explaining why certain populations are consistently at greater risk, it is also necessary to study factors external to the individual, including social, economic and

environmental factors (Bell & Schuurman, 2010). There is evidence to indicate that sports/leisure injuries might be associated with external factors such as ground conditions, environment and socio-economic status (Gabbett, Minbashian & Finch, 2007; Ni, Barnes & Hardy, 2002; Orchard, 2002). Further, studies have also indicated that the nature of the association between sports/leisure injuries and external factors is not universal and may differ according to the type of sport (Potter et al., 2005; Schmikli et al., 2009).

Participation in sports/leisure activities is often undertaken in purposely designed sports/leisure facilities. A healthy and welcoming environment may contribute to increased participation (Eime, Payne & Harvey, 2008) and lowers the risk of injury because of the support available in the facilities (Swan, Otago, Finch & Payne, 2009). Factors such as temperature, humidity, rainfall and ground hazards are associated with safe sports facilities (Cassell et al., 2003; Swan et al., 2009). Common ground hazards are ground hardness, poor maintenance of fields, surface irregularities and debris/rubbish; these hazards can be affected by weather patterns (Swan et al., 2009; Takemura, Schneiders, Bell & Milburn, 2007). For example, a study reported higher rates of injury in rugby during warm or dry conditions (Orchard, 2002). Another study supported this, discovering that injuries in rugby league matches are associated with less rainfall and harder ground conditions (Gabbett et al., 2007). Given this evidence, the proper maintenance and management of sport/leisure facilities, or in other words, the availability of safe sport/leisure facilities, could minimise the risk of injury. To do this, there is a need to identify the high-risk areas and affected populations.

It can be hypothesised that the availability of safe sport/leisure facilities depends on the social and economic characteristics of the region because people living in areas with higher socio-economic status (SES) are more likely to be able to afford sports club membership fees, clothing, equipment and so on compared to people living in low SES areas (Finch & Boufous, 2009). However, the relationship between sport injury rates and SES is still unclear (Finch & Boufous, 2009). A better understanding of the relationship between social and economic characteristics of the region and sport-specific sport/leisure injuries that occur at the population level is important to address the potential differences in injury rates and risk factors. For this, the application of geospatial analysis has been identified as a way to gain greater understanding of the complex nature of sport/leisure injuries and associated social, economic and environmental factors (Singh, Fortington, Eime, Thompson & Finch, 2015).

1.2 Geospatial Analysis in Epidemiological Investigation

Analyses performed on data that considers a geographic locational component (a reference location to the earth's surface) is referred to as geospatial analysis. Geospatial analysis provides a way to examine events, patterns and processes that occur in different populations (De Smith, Goodchild & Longley, 2007). Populations, or communities, have their own defining physical, environmental, lifestyle and socio-economic characteristics (Craglia & Maheswaran, 2016). These characteristics may have geographical variations that can help to describe patterns in the occurrence of a particular public health issue. Such issues could range from a global scale (e.g., the effect of climate change on health) to local issues (e.g., the identification of a contaminated water source for a cholera epidemic).

The application of geospatial analysis in public health has a long history dating back to 1854, when Dr John Snow applied a geospatial analysis method to investigate a cholera outbreak in London (Snow, 1855). Since then, geospatial analysis has been mostly used to understand the complex interplay between geospatially referenced health outcomes and explanatory variables. Geospatial analysis has been recognised by international organisations such as the WHO and European Commission for its importance in understanding the relationship between health outcomes and explanatory variables (Craglia & Maheswaran, 2016). Increased access to geospatial technologies and availability of geospatially referenced public health data has led to a significant increase in the use of geospatial methods to better understand public health issues, including injury (Auchincloss, Gebreab, Mair & Diez Roux, 2012; Singh, Fortington, Thompson & Finch, 2016).

Due to the complex nature of geospatial data and analysis, geographic information systems (GIS) are used to acquire, manipulate, analyse and store geographic information. A GIS is a combination of cartographic tools and spatial statistical methods for the management, analysis and presentation of spatial data (Nykiforuk & Flaman, 2011). The term GIS has been widely used in public health literature, often interchangeably with geospatial analysis. The application of GIS or geospatial analysis includes epidemiological investigation of public health issues, which are categorised into (i) disease mapping, (ii) disease clustering (iii) and ecological analysis (Lawson, Banerjee, Haining & Ugarte, 2016). These concepts are described in depth in Chapters 2 and 3 of this thesis, and demonstrated in Chapters 5–7.

1.3 Web-based Geospatial Visualisation of Public Health Data

It is crucial for decision-makers to have timely access to epidemiological information, along with information related to key health indicators (i.e., demographic, socio-economic and environmental), to facilitate evidence-based decision-making (Brownson, Fielding & Maylahn, 2009; Jacobs, 2012). In public health surveillance, data visualisation is a powerful tool to investigate trends and patterns hidden in large and complex data and to communicate the information to the broader public health community (Martinez, Ordunez, Soliz & Ballesteros, 2016). A map is a form of data visualisation commonly used to visualise spatially referenced data. Maps are most commonly presented in reports or published literature with limited spatial resolution, pre-rendered, in static form and can be difficult to understand, requiring expert knowledge. This has previously limited the use of spatial information by decision-makers (Joyce, 2009). However, with the development of web-based geospatial data visualisation tools to disseminate spatially referenced public health information (Cinnamon & Schuurman, 2010; Fu & Sun, 2010; Jardine et al., 2014; Shi, Zhang, Zhang, Wan & Shaw, 2007; Sopan et al., 2012), it is now possible to deliver timely and more user-friendly information to health professionals and policymakers (Gao, Mioc, Anton, Yi & Coleman, 2008). A web-GIS tool not only enables visualisation of raw data, it also supports investigation of trends and patterns through data visualisation. This allows decision-makers to tailor data outputs for their unique needs (Boulos, 2004). In summary, web-GIS is an efficient platform for disseminating geo-referenced data, enabling data to be used for evidence-based public health interventions.

1.4 Research Context

Sport/leisure injuries are identified as a significant public health burden globally (Conn et al., 2003; Finch & Cassell, 2006; Finch et al., 2015). Therefore, there have been sports/leisure injury prevention programs that have focused their attention on addressing either individual or community-level injury risks (Lauersen, Bertelsen & Andersen, 2014; Leppanen, Aaltonen, Parkkari, Heinonen & Kujala, 2014). However, despite considerable epidemiological inquiry, studies suggest an increasing trend in overall sport/leisure injury hospitalisations in Australia (Finch, Clapperton & McCrory, 2013; Finch et al., 2014). It is argued that current preventive efforts are not targeting the right communities (Finch et al., 2011). Additionally, there is a lack of involvement from government health departments and

specific public health policy to address injuries in the sports sector (Finch, 2011). This may be due to a lack of knowledge regarding the size and distribution of the problem or the communities that are consistently at greater risk of injury (Finch, 2011).

Geospatial methods are considered important in injury research to better understand target populations and complex relationships with external factors (Bell & Schuurman, 2010; Chong & Mitchell, 2009; Goltsman, Li, Bruce & Maitz, 2014). However, there is a gap in research (in Australia and globally) in the application of geospatial methods to better understand the epidemiology of sport/leisure injuries (Singh et al., 2016). Therefore, this research is focused on investigating sport/leisure injuries of Victoria, Australia using geospatial methods. The investigation will focus on Stage 1 (injury surveillance) and Stage 2 (identification risk and protective factors) from the geographical perspective. This thesis emphasises the potential for application of geospatial methods to provide a strong evidence base for research, strategic planning and development of injury prevention strategies.

1.5 Research Objectives

There are two main objectives of this research:

1. to examine the geospatial distribution of sport/leisure injury hospitalisations and their association with a broad range of social and economic characteristics using geospatial methods
2. to develop a web-GIS application for exploratory analysis of sports and leisure injury data

The first objective is addressed in Chapters 4–7 and the second objective is addressed in Chapter 8.

1.6 Thesis Structure

Chapter	Title	Aim	Research Questions	Objectives
1	Introduction			To provide context for the research undertaken and define the aims and research questions of this PhD thesis
2	Spatial epidemiology: A new approach for understanding and preventing sport injuries	AIM 1: To identify the potential application of geospatial methods in sport/leisure injury epidemiological investigation	How can geospatial methods be applied in epidemiological investigation of sport/leisure injuries?	To describe the potential application of the spatial epidemiological approach in sports injury prevention
3	An overview of geospatial methods used in unintentional injury epidemiology	AIM 2: To conduct a review of geospatial methods applied in unintentional injury epidemiological studies with a specific sub-aim to determine if they had previously been applied to sport/leisure injury data	1) What are the most commonly used geospatial methods in unintentional injury epidemiological studies? 2) Have any geospatial methods been applied to investigate sport/leisure injuries?	To provide an overview of geospatial methods used in unintentional injuries and to identify whether geospatial methods are applied to investigate sport/leisure injuries
4	Overview of sport/leisure injury data			To describe the research area and data used in this study
5	Geographical mapping of sports and leisure injury hospitalisations as related to socio-economic status and remoteness regions	AIM 3: To examine the sport/leisure injury hospitalisations by LGA of Victoria in relation to socio-economic status and remoteness regions	What is the distribution of sport/leisure injury hospitalisation rates by LGA and how are the sport/leisure injury hospitalisation rates distributed across socio-economic and remoteness regions?	To describe the sport/leisure injury hospitalisation rates by LGA of Victoria and examine the sport/leisure injury hospitalisations by socio-economic and remoteness regions
6	Use of geographic analysis to identify areas presenting high risk of sport/leisure injury	AIM 4: To identify hot spots (LGAs with high sport/leisure injury hospitalisation rates surrounded by other LGAs with high sport/leisure	1) Are there any hot and cold spots? If so, where are the location of these? 2) What are the differences in	To identify high-burden LGAs (those surrounded by other high-burden LGAs) (hot spots) and low-burden LGAs (those

	hospitalisations	injury hospitalisation rates) and cold spots (LGAs with low sport/leisure injury hospitalisation rates surrounded by other LGAs with low sport/leisure injury hospitalisation rates) and examine the differences in sport/leisure injury hospitalisations by demographic and injury characteristics of the hot and cold spot regions	sport/leisure injury hospitalisations by demographic and injury characteristics in identified hot and cold spot regions?	surrounded by low-burden LGAs) (cold spots) and examine the differences in sport/leisure injury hospitalisations by demographic and injury characteristics of the hot and cold spot regions
7	Investigating the relationship between neighbourhood characteristics and sport and leisure injury hospitalisations using geospatial analysis methods	AIM 5: To investigate whether any observed spatial pattern of sport/leisure injury hospitalisations is associated with spatial differences in neighbourhood characteristics such as socio-economic factors and education	What is the nature of association between sport/leisure injury hospitalisations and area-level neighbourhood characteristics such as socio-economic factors and education?	To investigate whether any observed spatial pattern of sport/leisure injury hospitalisations are attributable to the spatial differences in diversity, education, income and social-engagement characteristics
8	Spatially enabling sports and leisure injury data of Victoria: An evidence tool policy formation	AIM 6: To develop a web-GIS application for exploratory analysis of sports and leisure injury data	What are the benefits of developing web-GIS applications for exploratory analysis of sport/leisure injury hospitalisations?	To develop a web-GIS application for exploratory analysis of sports and leisure injury data
9	Discussions and conclusions			To discuss the research findings, implications, methodological strengths and limitations, and future research directions

Chapter 2: Spatial Epidemiology: A New Approach for Understanding and Preventing Sport Injuries


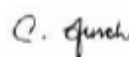



2.1 Overview

The first law of geography states that ‘everything is related to everything else but near things are more related than distant things’ (Tobler, 1970). According to this, in the injury context, it is expected that an area with high injury occurrences would be surrounded by areas with high injury occurrences because of similarities in neighbourhood environmental and contextual factors. The traditional epidemiological investigation is not sufficient to test this hypothesis. Further, the science of injury research relies on data, and such data have traditionally been examined using a statistical approach. The standard statistical approach does not consider geospatial patterns that may exist within the data. For example, two datasets may be identical from a statistical view, but the spatial pattern of those datasets may be different. Therefore, it is important to better understand the complex nature of injury and the associated diverse range of risk factors. The spatial epidemiological approach is an emerging discipline in injury research that addresses epidemiological questions from a geographic perspective. This chapter discusses the potential application of the spatial epidemiological approach for better understanding and prevention of sport injuries. This material was published as a journal paper in the *Australasian Epidemiologist* in 2015.

2.2 Declaration

Table 2.1 outlines the authors who contributed to this work.

Table 2.1: Contributing authors to *Australasian Epidemiologist* article

Name	Nature of contribution	Contribution (%)	Sign	Date
Himalaya Singh	Responsible for the concept and the writing of the manuscript	70		09/03/2018
Caroline F Finch	Contributed further ideas and editorial input	10		13/03/2018
Lauren V Fortington	Contributed further ideas and editorial input	10		13/03/2018
Helen Thompson	Contributed further ideas and editorial input	5		13/03/2018
Rochelle Eime	Contributed further ideas and editorial input	5		13/03/2018

2.3 Abstract

To develop effective strategies to prevent sports injuries, we need to understand the people and populations most at risk of injury as well as the risk factors associated with sustaining injury. Spatial epidemiology is a method used to address questions of when, where, to whom and how health outcomes such as sports injuries occur at a population level, taking into account geographic variation. The aim of this article is to outline the potential application of spatial epidemiology to achieve a better understanding of sports injuries to inform prevention strategies.

2.4 Introduction

Encouraging people to participate in sport and recreational activities is a public health priority in Australia and around the world for the promotion of good health and wellbeing (Kohl, Craig & Lambert, 2012; Warburton, Nicol & Bredin, 2006). However, sports participation is also associated with a risk of sustaining an injury (Finch & Owen, 2001). Sports injuries are a significant public health problem, with every fifth unintentional injury associated with a sports activity (Conn et al., 2003). Economic costs are estimated to be around AUD1.8 billion per annum and are increasing significantly every year (Finch et al., 2015; Finch et al., 2013; Finch, Mitchell & Boufous, 2011). To develop strategies to prevent sports injuries, better identification of which communities, populations or sporting groups should be the target of preventive efforts is needed. There is also a need to better understand population-level risk factors for these injuries to inform the content and focus of preventive measures.

Epidemiological information about where, when, to whom and how injuries occur is crucial for strategic planning and development of injury prevention programs (Cusimano, Chipman, Glazier, Rinner & Marshall, 2007). The specialist field of spatial epidemiology provides information to address those questions at a population health level. The first example of spatial epidemiology dates back to the mid-18th century, when the well-known map of cholera cases was produced by Snow (1855). Since then, and with development of more advanced information technologies, spatial epidemiological research methods have been used in many studies, including injury research (Ha & Thill, 2011; Williams, Schootman, Quayle, Struthers & Jaffe, 2003). However, there are very few examples of spatial epidemiology having been used in the sports injury field. The aim of this article is to outline the potential

application of spatial epidemiology for a better understanding of sports injuries and their prevention.

2.5 Spatial Epidemiology

Spatial epidemiology is the study of health outcomes in relation to geographic variation in risk factors (Elliott & Wartenberg, 2004). A range of descriptions and terms relating to spatial epidemiology have been used in past research including GIS, mapping, spatial analysis, geographic analysis, and geospatial analysis. While terminology has varied, what is common to all spatial epidemiological studies is the underlying concept of spatial data having a geographic reference point. Put simply, spatial epidemiology is a combination of epidemiology, statistics and geographic information science (Beale, Abellan, Hodgson & Jarup, 2008).

Spatial epidemiology can be broadly divided into three different elements – injury mapping, clustering and injury modelling, as shown in Figure 2.1. In the context of injury epidemiology, spatial approaches have been applied to investigate injuries such as burns, drowning, violent trauma and those sustained in road traffic crashes (Dai, 2012; Dai, Zhang, Lynch, Miller & Shakir, 2013; Poulos, Hayen, Chong & Finch, 2009; Walker, Schuurman & Hameed, 2014). Such research has identified high-risk areas and explored relationships with socio-economic and environmental risk factors. Similarly, for sports injury research, studies could look at addressing questions of high-risk areas or geographically linked risk factors for sustaining an injury in a team or individual sport.

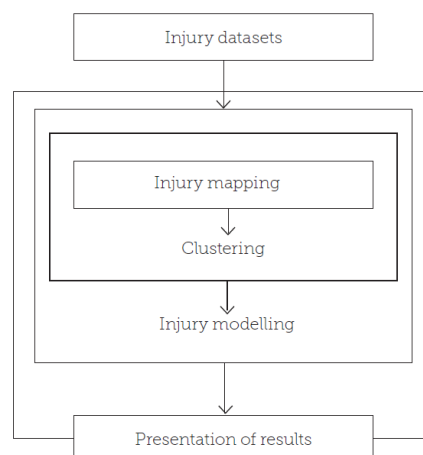


Figure 2.1: Elements of spatial epidemiology and their flow for application to sports injury epidemiology

2.6 Injury Mapping

Mapping is one element of spatial epidemiology used to understand and visualise complex spatial structures in data (Cleveland, 1993). Injury datasets are represented on a map, through either point or areal data formats. Point data represents a single event in a geographical space, whereas areal data represents events aggregated to a well-defined geographical unit, such as postcodes, LGA and statistical areas. A dot, dot-density or heat map can be used to represent point data, whereas choropleth and continuous maps of standardised rates and other measures of injury occurrence are used to represent areal data (Jerrett et al., 2003).

Mapping is a potentially useful method to gain an understanding of the spatial pattern of sport injuries. As an example, Figure 2.2 shows a choropleth map, generated from illustrative sport injury data applied to Victoria, Australia. Using random numbers to represent sports injuries as the numerator and Australian Bureau of Statistics population data from 2010–11 as the denominator, the map demonstrates how population-adjusted sports injury incidence rates can be visualised for a region. The darkest areas indicate high injury incidence rates and the lighter areas indicate a low injury incidence rate.

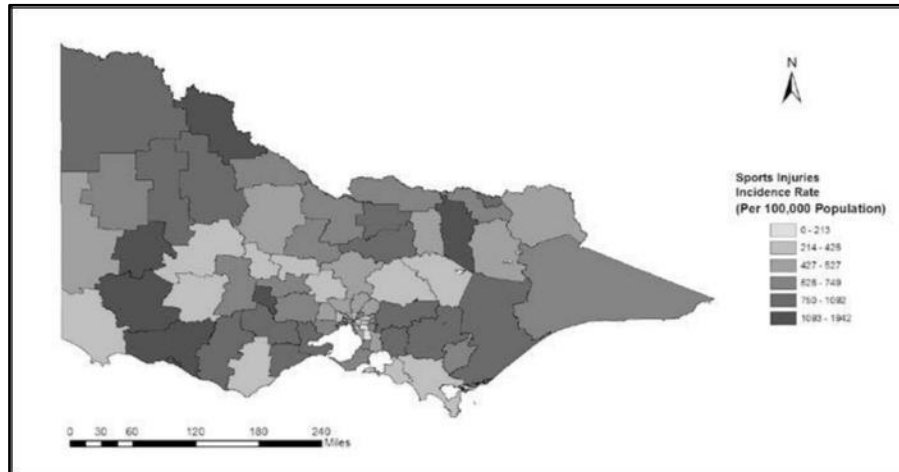


Figure 2.2: An example map showing simulated population standardised sports injury rates (per 100,000) for Victoria

Data sources: Injuries (numerators) are simulated example data. Population data (denominators) are actual total population of Victoria by local government area on 30 June 2010 – www.abs.gov.au/.

2.7 Clustering or Cluster Detection

Clustering or cluster detection involves an assessment of the distribution of disease occurrence across a study area to identify high-risk areas and low-risk areas (Rezaeian, Dunn, St Leger & Appleby, 2007). There are two main types of methods for this assessment: global and local (Fritz, Schuurman, Robertson & Lear, 2013). Global methods identify the nature of the overall distribution whereas local methods identify the actual location of the clusters. Many cluster detection methods have been developed in the last two decades for point or areal data such as K-function, Moran's *I*, Getis-Ord G_i^* and spatial scan statistics. To demonstrate the application of clustering to sports injuries, the Getis-Ord G_i^* method was applied to the example sports injury data for Victoria. This method identifies statistically significant clusters of high values and low values by calculating G_i^* statistics for each feature in the dataset, which are returned as a z-score. A larger z-score is representative of clustering of high values, also known as hot spots. Smaller Z-scores are representative of clustering of lower values, or cold spots. The result is presented in Figure 2.3 with dark areas indicating hot spots, in which higher sports injury incidence rates are observed and light areas indicating cold spots, with lower sports injury incidence rates.

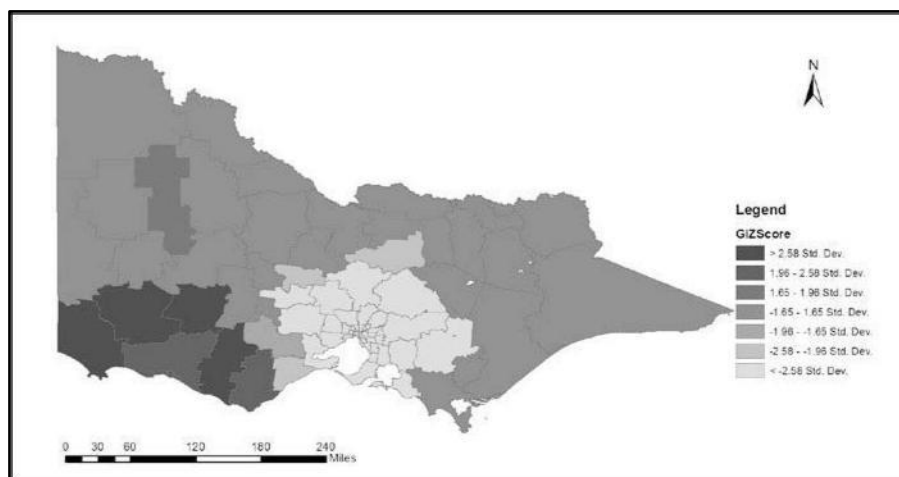


Figure 2.3: Cluster detection analysis (using Getis-Ord G_i^*) applied to example sports injury data for Victoria

Data sources: Injuries (numerators) are simulated example data. Population data (denominators) are actual total population of Victoria by local government area on 30 June 2010 – www.abs.gov.au/.

2.8 Injury Modelling

Injury modelling is concerned with examining and modelling the relationship between a dependent variable and a set of one or more independent variables, i.e., risk factors. To date, the majority of sports injury aetiological epidemiology studies have focused on immediate or internal factors for injury risk, i.e., factors within the individual's control such as equipment, training-related behaviour and adherence to rules/regulations (McBain et al., 2012). However, it is also known that external factors, such as socio-economic and environmental characteristics can have an impact on sports injury risk (Finch & Boufous, 2009; Orchard, 2002; Gabbett et al., 2007).

Ordinary least square regression (OLS), a global modelling technique, is a widely used statistical technique for investigating relationships between variables (Montgomery, Peck & Vining, 2012). However, OLS and other generalised linear models (GLM) do not take into account spatial autocorrelation that may be present in injury data, and could lead to biased regression coefficient estimates (Erdogan, 2009; Fotheringham, Charlton & Brunsdon, 1998; Nkeki & Osirike, 2013). Geographically weighted regression (GWR), also known as a disaggregate spatial regression technique, has been developed to account for spatial autocorrelation neglected by GLMs (Fotheringham et al., 1998). Future application of GWR to sports injury data will have the potential to better describe the relationship between external risk factors and injury occurrence and is the focus of work currently underway by our team.

2.9 Conclusion

Novel applications of spatial epidemiological approaches to sports injury data will offer significant benefits for injury surveillance, allocation of resources and development of effective prevention programs because of better identification of target groups and population-level risk factors that influence injury patterns. With increasing availability and quality of spatially referenced data for sports injuries, as well as population, environmental and socio-economic risk factors, there is a clear opportunity to apply spatial epidemiological methods to sports injury data in Australia.

2.10 Acknowledgements

Himalaya Singh was supported by a Federation University Australia Postgraduate Scholarship. This work is part of his PhD work, under the supervision of the co-authors. Caroline Finch was supported by a National Health and Medical Research Council (NHMRC) Principal Research Fellowship (ID: 1058737). The Australian Centre for Research into Injury in Sport and its Prevention (ACRISP) is one of the international research centres for the prevention of injury and protection of athlete health supported by the International Olympic Committee.

2.11 Summary

This chapter provides valuable insight into the potential of spatial epidemiological applications as a novel approach in the context of sport/leisure injuries. It was important to discuss the potential application of the spatial epidemiological approach because preliminary investigations highlighted that this approach has had very limited application in sport/leisure injury research. Three main application areas of spatial epidemiological approaches (mapping, cluster detection and ecological analysis) were identified for their potential to investigate spatial patterns of sport/leisure injuries and each approach was briefly discussed.

Spatial epidemiological approaches offer significant benefits for resource allocation, injury surveillance and development of injury prevention programs. This chapter also demonstrates how these approaches are useful for investigating spatial patterns and identifying geographical areas that are consistently at greater risk. However, this chapter does not provide the details of their application in sport/leisure injuries and to broader unintentional injury epidemiological studies. Therefore, Chapter 3 focuses on reviewing the studies that used one or more themes of spatial epidemiology to unintentional injuries.

Chapter 3: An Overview of Geospatial Methods Used in Unintentional Injury Epidemiology

3.1 Overview


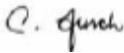


A spatial epidemiological approach is identified as a novel approach to investigate the spatial pattern of sport/leisure injuries. The three main application areas of the spatial epidemiological approach are mapping, clustering and cluster detection, and ecological analysis. The methods used in each theme are considered geospatial methods because they consider the geographic location of the events.

Many studies have highlighted the importance of the spatial epidemiological approach in injury prevention in gaining a greater understanding of the complex nature of injury and the associated diverse range of geographic risk factors (Auchincloss et al., 2012; Bell & Schuurman, 2010; Cusimano et al., 2007; Ostfeld, Glass & Keesing, 2005). However, there is limited research that explores the use of spatial epidemiological approaches in unintentional injury epidemiological studies. Therefore, the aim of this chapter is to summarise the use of the spatial epidemiological approach in unintentional injury epidemiological studies. This chapter has been published in full as a peer-reviewed paper in the journal *Injury Epidemiology* in 2016.

3.2 Declaration

Table 3.1 outlines the authors who contributed to this paper.

Table 3.1: Contributing authors to *Injury Epidemiology* article

Name	Nature of Contribution	Contribution (%)	Signature	Date
Himalaya Singh	Responsible for the concept and writing of the manuscript	75		09/03/2018
Caroline F Finch	Contributed further ideas and editorial input	10		13/03/2018
Lauren V Fortington	Contributed further ideas and editorial input	10		13/03/2018
Helen Thompson	Contributed further ideas and editorial input	5		13/03/2018

3.3 Abstract

Background: Injuries are a leading cause of death and disability around the world. Injury incidence is often associated with socio-economic and physical environmental factors. The application of geospatial methods has been recognised as important to gain greater understanding of the complex nature of injury and the associated diverse range of geographically diverse risk factors. Therefore, the aim of this paper is to provide an overview of geospatial methods applied in unintentional injury epidemiological studies.

Methods: Nine electronic databases were searched for papers published in 2000–2015, inclusive. Included were papers reporting unintentional injuries using geospatial methods for one or more categories of spatial epidemiological methods (mapping; clustering/cluster detection; and ecological analysis). Results describe the included injury-cause categories, types of data and details relating to the applied geospatial methods.

Results: From over 6,000 articles, 67 studies met all inclusion criteria. The major categories of injury data reported with geospatial methods were road traffic ($n = 36$), falls ($n = 11$), burns ($n = 9$), drowning ($n = 4$), and others ($n = 7$). Grouped by categories, mapping was the most frequently used method, with 62 (93%) studies applying this approach independently or in conjunction with other geospatial methods. Clustering/cluster detection methods were less common, applied in 27 (40%) studies. Three studies (4%) applied spatial regression methods (one study using a conditional autoregressive model and two studies using GWR) to examine the relationship between injury incidence (drowning, road deaths) with aggregated data in relation to explanatory factors (socio-economic and environmental).

Conclusion: The number of studies using geospatial methods to investigate unintentional injuries has increased over recent years. While the majority of studies have focused on road traffic injuries, other injury-cause categories, particularly falls and burns, have also demonstrated the application of these methods.

Geospatial investigations of injury have largely been limited to mapping of data to visualise spatial structures. Use of more sophisticated approaches will help to understand a broader range of spatial risk factors, which remain under-explored when using traditional epidemiological approaches.

Keywords: Geographical epidemiology, Spatial epidemiology, Mapping, Spatial analysis, Smoothing, Clustering, Cluster detection, Geographical correlation, Ecological analysis

3.4 Review

3.4.1 Background

Injury is a leading preventable cause of death and disability around the world (Peden, McGee & Krug, 2002). Previous epidemiological studies have demonstrated that injury incidence is often related to external socio-economic and physical environmental factors (Muller et al., 2005; Poulos et al., 2007). Unlike many non-communicable health-related conditions, the incidence of many injuries can also be directly linked to specific places (e.g., body of water, road intersection, junctions) (Dai et al., 2013; Lai et al., 2011; Zhang et al., 2015). Therefore, to better understand injury causation, it is important to account for the interplay between social and environmental risk factors in relation to their geographic (or spatial) distribution (Bell & Schuurman, 2010). GIS tools and geospatial analysis methods can be used to investigate these spatial risk factors, which have been under-explored in traditional epidemiological studies (Beale et al., 2008; Ostfeld et al., 2005).

Geospatial methods have a long history of use in public health, including for epidemiological research (Auchincloss et al., 2012; Lawson, 2001). Within this area, termed spatial epidemiology, investigations can be characterised by three broad categories of enquiry: (i) mapping; (ii) clustering/cluster detection (hot spot analysis); and, (iii) ecological analysis (Elliott & Wartenberg, 2004; Lawson, 2001; Lawson et al., 2016; Singh et al., 2015). These categories are interrelated, and may overlap in some cases, so they should not be considered as distinct components (Elliot et al., 2000; Lawson et al., 2016).

3.4.2 Category 1: mapping

Mapping has primarily been used to describe disease incidence in a spatial context and subsequently, to formulate aetiological hypotheses by identifying areas of high-risk (Elliot et al., 2000; Lawson et al., 2000). The choice of map depends largely on the spatial resolution of the available data. In public health, this data tends to be based on specific point features (e.g., residential addresses or coordinates of disease location) or aggregated by areal features (e.g., state, county, local government area or postcode.) To represent point data, a point map is commonly used, in which each individual case is represented by a single

point on a map relative to its geographic location (Waller & Gotway, 2004). This is useful when study aims include understanding how individual cases are distributed geographically. To represent attribute information associated with individual cases, other types of point maps can be used such as graduated colour maps where a range of colours (e.g., blue to red) indicate a progression of numeric values. Where areal data is available, the choropleth map is commonly used, in which different colour patterns are applied to regions representing a class of values (Waller & Gotway, 2004).

Other types of maps, such as classed symbol maps, are less commonly used. Most commonly, disease data is available as aggregated summaries for areal features such as postcode, census tract or counties (Beale et al., 2008). Statistical techniques are then applied to estimate area-level risks, and those estimates are mapped to understand the spatial distribution of risk. The most common summary measures of occurrence are frequency, incidence rates, standardised mortality ratio and relative risk (Beale et al., 2008). When counts or rates are large, their distributions follow statistical assumptions inherent in linear models. However, if the counts or rates are small, as is the case in some areas, the application of appropriate smoothing techniques are required to address the small number problem (Waller & Gotway, 2004).

3.4.3 Category 2: clustering/cluster detection

Clustering/cluster detection refers to the uncovering of ‘unusual’ aggregation of disease incidence (Fritz et al., 2013; Lawson, 2001). These methods are applied to investigate how health outcome data relate spatially by identifying: (i) the presence of any clusters, in which case global (general, non-specific) methods are used; and, (ii) the location of clusters in space, for which local (focused, specific) methods are used (Lawson, 2001; Lawson et al., 2016). Usually, global methods generate an autocorrelation parameter that defines the nature of the spatial pattern whereas local methods identify the specific locations of clusters, also known as hot spots. Many clustering/cluster detection methods have been developed based on different statistical models specific for point and/or areal features within the two broad categories of global and local (Fritz et al., 2013). Such methods are underpinned by different statistical approaches, so each method could provide different clustering/cluster results for the same set of data (Waller & Gotway, 2004).

A review that summarised the clustering/cluster detection methods most commonly applied in epidemiology identified Diggle and Chetwynd’s bivariate K-function, Mantel-Bailear’s test

and the Potthoff-Whittinghill method as the most preferred global methods and spatial scan statistics as the most preferred local method (Auchincloss et al., 2012). A more recent summary reviewed cluster methods applied in epidemiology for point data and identified that the

K-function is the most commonly used global method followed by methods based on the nearest neighbour statistics such as nearest neighbour index (NNI), nearest neighbour hierarchical (NnH) and Cuzick Edwards' test (Fritz et al., 2013). The study also reported the most common local method to be spatial scan statistics (Fritz et al., 2013). Other methods have also been used in broader public health applications such as kernel density estimation, Moran's *I*, Local Indicator of Spatial Autocorrelation (LISA), Getis-Ord statistics, and Tango's maximised excess events test (Auchincloss et al., 2012; Fritz et al., 2013). Each clustering/cluster detection method has its own strengths and weaknesses and may not be appropriate to all datasets because each dataset differs in spatial resolution (point or areal), spatial coverage (area covered by dataset) and spatial intensity (distribution of outcome of interest) (Fritz et al., 2013; Waller & Gotway, 2004).

3.4.4 Category 3: ecological analysis

Ecological analyses examine the spatial distribution of disease incidence in relation to explanatory factors (Lawson et al., 2016). These types of studies use spatial statistical models to investigate the relationship between exposures and disease at an aggregate level (Elliot et al., 2000; Lawson et al., 2016). Importantly, traditional statistical models may not be appropriate for the analysis of spatially dependent data because of their inability to address or account for spatial autocorrelation and/or spatial heterogeneity. Therefore, spatial regression models have been developed under both frequentist and Bayesian approaches, with common methods used in epidemiological studies being Conditional Autoregressive Models (CAR), GWR and the Besag York and Mollié (BYM) approach (Auchincloss et al., 2012; Chaney & Rojas-Guyler, 2016; Rezaeian et al., 2007). These methods differ in their complexity of computation, approach towards capturing spatial heterogeneity, and in how they quantify the uncertainty associated with parameter estimates (Auchincloss et al., 2012).

3.4.5 Aim of the review

While the principles of geospatial analysis have broad relevance to injury epidemiology, their application to injury data is still relatively novel (Bell & Schuurman, 2010; Cusimano et al.,

2007; Singh et al., 2015). One possible reason for this could be that geospatial analysis requires spatially referenced health and determinant data at a population level (Beale et al., 2008; Bell & Schuurman, 2010). With widespread use of global positioning system (or GPS) technologies over the past decade, these data have become increasingly available and can now be linked to injury data sets. In addition, wider accessibility to GIS for the management, analysis and presentation of spatial data has also increased in the last decade, with capability now (at least partially) incorporated into standard statistical software (e.g. STATA (StataCorp, 2015)) or available through open-source platforms (e.g., QGIS (QGIS 2015), GeoDa (Anselin et al., 2006), SatScan (Kulldorff et al., 1998) and CrimeStat (Levine, 2000)). Given the increase in availability of both spatially referenced injury data and GIS software, it is timely to consider how and when geospatial methods have been applied to injury epidemiology studies.

A previous review summarised the history of GIS in relation to injury prevention (Bell & Schuurman, 2010), but that review did not include details about the actual geospatial methods used in the published literature. Therefore, the aim of this study is to summarise the application of geospatial methods to unintentional injury as found in epidemiological studies published since 2000. The focus is on the type of analysis and/or data representation approach used, rather than on the injury incidence estimates per se. The intention is for these new review findings to help inform future research agendas in injury prevention.

3.5 Methods

The publication search was guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). As the aim was to summarise the geospatial analysis methods reported in each study, some items of the PRISMA statement were not applicable (e.g., there was no formal assessment of risk of bias), nor was a quality assessment of the reviewed studies undertaken given the focus was on the adopted analysis methods only.

3.5.1 Search strategy

The focus of the review was restricted to unintentional injury studies given the strong link between the occurrence of such events and a specific single geographical location (e.g., a road intersection, body of water). A comprehensive list of MeSH (Medical Subject

Headings) terms and free text keywords relating to geospatial methods and unintentional injury incidence were used to develop a search strategy (Appendix 1). Nine electronic databases were searched: Medline, Academic Search Complete, CINAHL Complete, Engineering Source, GeoRef, Health Source: Nursing/Academic Edition, PsycINFO, SPORT Discus with Full Text, Web of Science.

3.5.2 Study selection and eligibility

Standardised inclusion and exclusion criteria were formulated (Appendix 1) and independently applied by two authors to scan the title and abstract of all search results. Any publication deemed potentially eligible was included for full text review.

Full text review determined if studies investigated unintentional injuries using geospatial methods to address one or more of the following aims:

- to describe the geographical/spatial variation of injury incidence
- to test for clustering or to identify clusters
- to address aetiological questions (provide aetiologic cues about the relationship between the spatial distribution of injury incidence and explanatory factors at the aggregate level).

There was a large number of studies initially included that were subsequently identified as not reporting injury data. In particular, there were a large number of road transport studies that reported data in terms of crashes, collisions or accidents rather than reporting the frequency or rate of the injuries sustained during such events (Blazquez & Celis, 2013; Zhang et al., 2015). Only studies where injuries were clearly identifiable were retained (as opposed to those with a focus on potential injury-causing events). Original peer-review studies, published in 2000 to 2015, were included.

Studies that investigated intentional injuries, such as suicides or violence, were not included. We have excluded studies focused on assessing spatial access to trauma centres because our aim is to summarise methods used for epidemiological investigation rather than those associated with healthcare resource planning.

3.5.3 Data extraction

Descriptive data from each study were extracted by the first author (Appendix 2). Where information was unclear or inconsistent, it was discussed with co-authors until agreement was reached on an outcome. The extracted data and definition of terms sought from each study were:

- First author and year of publication: to identify specific studies and to assess the use of geospatial methods over time.
 - Injury causes: to categorise each study as being focused on one or more of the following external cause categories—road traffic, falls, drowning, burns, poisoning, natural disasters, and others (including combined causes).
 - Data coverage: to identify the source of the data and its geographic location.
 - Name of the GIS package used to analyse the spatial data.
 - Study classification: Studies were classified into one or more of the three broad categories of spatial epidemiological approaches, and relevant details of the methods applied in each category were extracted.
1. Mapping studies: To be classified in this category, studies had to report one or more maps representing raw injury data or results derived from statistical models applied to that injury data for descriptive purposes. The information extracted from each paper included data relevant to the type of map (e.g., point, choropleth, classed symbol), the summary measure considered (e.g., incidence rates, standardised mortality ratio) and any smoothing technique (e.g., empirical Bayes method, BYM) applied.
 2. Clustering/cluster detection studies: To be included in this category, studies had to apply one or more methods to the injury data to test for clustering (as a measure of spatial autocorrelation or spatial heterogeneity or spatial dependency) or to identify clusters (also known as hot spots). Information regarding each method in terms of its spatial resolution (point or areal), and approach (global or local) were extracted.
 3. Ecological studies: To be classified in this category, studies had to apply one or more spatial regression methods to address aetiological questions with the question clearly stated in the study objective. The applied method, as well as the dependent and type of explanatory variables used in the analysis, were extracted.
 - 4.

3.5.4 Analysis of extracted data

Studies were grouped by injury-cause categories, publication year and geospatial analysis approach/es. Summaries of the extracted data were tabulated and summarised in text.

3.6 Results

From more than 6,000 publications identified, 67 studies met all criteria for inclusion (see Figure 3.1).

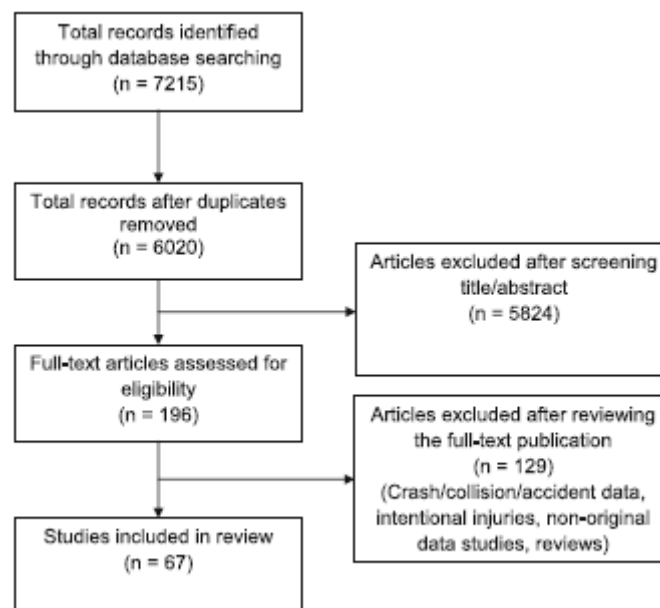


Figure 3.1: Flowchart of selection process for studies that applied geospatial methods to investigate unintentional injuries

The majority of studies were concerned with road traffic injuries (n = 36) (Chakravarthy et al., 2010; Cinnamon et al., 2011; DiMaggio, 2015; Dissanayake et al., 2009; Durkin et al., 2005; Eksler & Lassarre, 2008; Eksler et al., 2008; Erdogan, 2009; Haynes et al., 2005; Haynes et al., 2008; Hajar et al., 2003; Hosking et al., 2013; Hu et al., 2008; Huff et al., 2012; Jones et al., 2008; La Torre et al., 2007; Lassarre & Thomas, 2005; Lateef, 2011; Lawrence et al., 2015; Mohan et al., 2015; Morency & Cloutier, 2006; Nagata et al., 2011; Nunes & Nascimento, 2012; Nunn & Newby, 2015; Paulozzi, 2006; Poulos et al., 2012; Razzak et al., 2011; Schuurman et al., 2009; Silva et al., 2011; Slaughter et al., 2014; Spoerri et al., 2011; Statter et al., 2011; Sukhai et al., 2009; Unni, Morrow & Schultz et al., 2012; Weiner & Tepas, 2009; Yan-Hong et al., 2006).

Other studies considered falls ($n = 11$) (Bamzar & Ceccato, 2015; Chan et al., 2012; de Pina et al., 2008; Dey et al., 2010; Lai et al., 2009a; Lai et al., 2009b; Lai et al., 2011; Morency et al., 2012; Towne et al., 2015; Turner et al., 2009; Yiannakoulis et al., 2003), burns ($n = 9$) (Edelman et al., 2010; Fouillet et al., 2006; Goltsman et al., 2014; Harlan et al., 2013; Heng et al., 2015; Mian et al., 2014; Niekerk et al., 2006; Stylianou et al., 2015; Williams et al., 2003), drowning ($n = 4$) (Dai et al., 2013; Maples & Tiefenbacher, 2009; Sharif et al., 2012; Shenoï et al., 2015), occupational ($n = 2$) (Breslin et al., 2007; Forst et al., 2015), aviation-related ($n = 2$) (Grabowski et al., 2002a, 2002b), poisoning ($n = 1$) (Nkhoma et al., 2004), natural disaster ($n = 1$) (Peek-Asa et al., 2000) and dog-bite ($n = 1$) (Raghavan et al., 2014).

3.6.1 Adopted geospatial analysis approaches

Mapping was the most common approach applied to the geospatial data, being reported in 93% ($n = 62$) of the included publications. Clustering or clustering detection methods were used in 40% ($n = 27$) and spatial regression methods for ecological analysis were applied in only 4% ($n = 3$) of studies. As Table 1 shows, some studies used >1 approach, so the percentage of studies using each approach does not sum to 100%. Most of the studies ($n = 46$, 67%) reported only one analysis approach, most commonly mapping, but 18 (27%) used two approaches and three (4%) studies reported all approaches.

Table 3.2: Number of studies ($n = 67$) across the three categories: mapping, clustering/cluster detection and ecological analysis

	Spatial epidemiological approach categories			Total studies
	Mapping	Clustering/cluster detection	Ecological analysis	
Mapping only	√	-	-	41
Cluster only	-	√	-	5
Mapping/cluster	√	√	-	18
All categories	√	√	√	3
Total approaches	62	27	3	67 ^a
				92 ^a

^a The total number of approaches ($n = 92$) is not equal to the total number of studies ($n = 67$) because some studies applied multiple approaches.

The year of publication for the included studies, overall and by combination of categories, is presented in Figure 3.2. There was an overall trend towards increased use of geospatial

methods, especially clustering, since 2008, demonstrated by the increasing number of studies that applied both mapping and clustering/cluster detection methods.

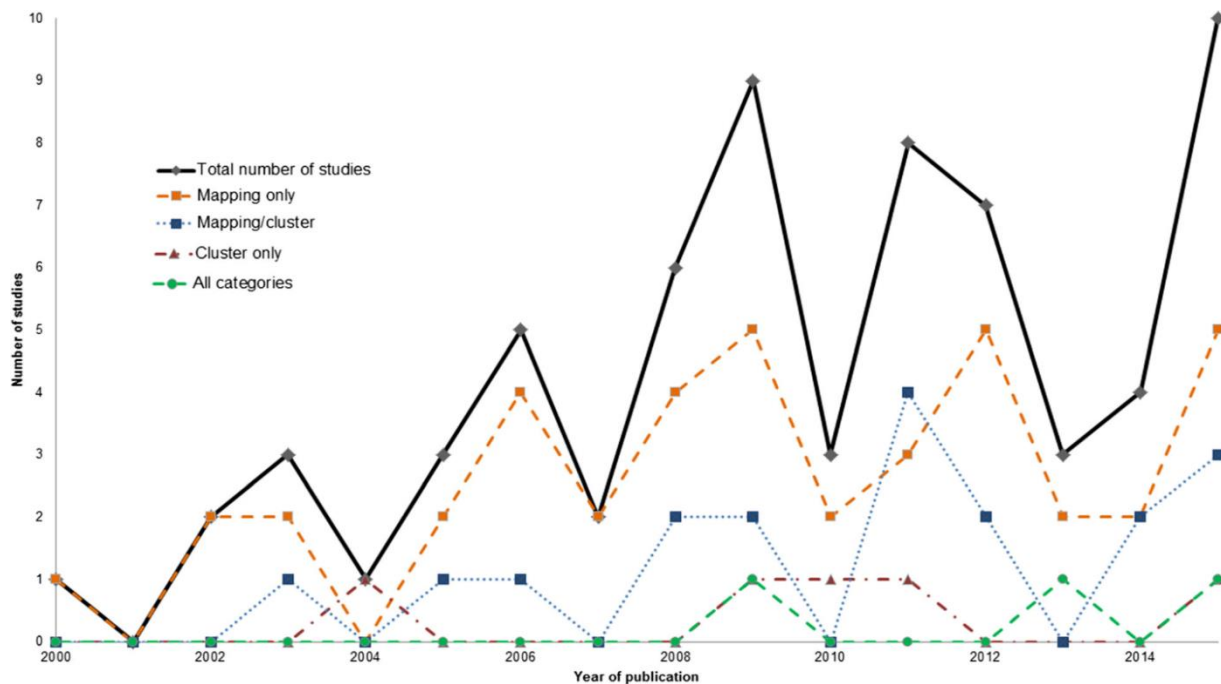


Figure 3.2: Application of geospatial analysis methods to unintentional injury data since 2000 (n = 67 studies)

3.6.2 Mapping studies

Of the 62 studies identified as using mapping (Table 2), the injury-cause categories most frequently investigated were road crashes (n = 33), falls (n = 10), burns (n = 9), drowning (n = 4), occupational (n = 2), aviation-related (n = 2), dog-bite (n = 1) and natural disaster (n = 1). Of the mapping studies, 15 studies presented dot maps of specific injury locations, 50 studies presented summary measures of aggregated data in choropleth (n = 47) and classed symbol

(n = 3) maps. Three of the included studies presented two types of maps (dot and choropleth) so the sum of this group is not equal to the total number of studies (n = 65 types of maps, n = 62 studies). The choropleth and classed symbol maps represented different types of summary measures: incidence rate (n = 27), relative risk (n = 10), frequency (n = 8), and standardised mortality ratios (n = 6). One study mapped more than one summary measure, namely, incidence rate and relative risk (Williams et al., 2003), so again, the sum by summary measures (n = 48) does not equal the total number of studies (n = 47) presented choropleth maps.

Table 3.3 summarises the types of maps and summary measures within the included studies. Most studies presented multiple maps as figures within the manuscript, representing the different variables under investigation. In 13 studies, different smoothing techniques were applied to address a small number problem. Methods used were an empirical Bayes model ($n = 5$) (de Pina et al., 2008; Erdogan, 2009; Lassarre & Thomas, 2005; Silva et al., 2011; Yiannakoulis et al., 2003), Bayesian model ($n = 4$) (Eksler & Lassarre, 2008; Eksler et al., 2008; Turner et al., 2009; Williams et al., 2003), BYM ($n = 3$) (DiMaggio, 2015; Heng et al., 2015; Poulos et al., 2012) and Poisson regression model ($n = 1$) (Spoerri et al., 2011). The most commonly used empirical Bayes method (Clayton & Kaldor, 1987) determines the extent of smoothing from the underlying structure of data including the crude standardised mortality ratio, its precision and the underlying relative risk distribution. In contrast, the BYM approach (Besag et al., 1991) considers both spatial effects (spatial dependency) and heterogeneous effects (spatial independence) to estimate smoothed rates.

Table 3.3: Number of studies presenting injury maps and the type of measure represented ($n = 62$ studies)

	Type of map		
	Dot	Choropleth	Classed symbol
Injury cause categories			
Road traffic ($n = 33$)	10	24	1
Falls ($n = 10$)	3	6	1
Burns ($n = 9$)	-	8	1
Drowning ($n = 4$)	1	3	-
Occupational ($n = 2$)	-	2	-
Aviation-related ($n = 2$)	-	2	-
Natural disasters ($n = 1$)	1	1	-
Dog-bite ($n = 1$)	-	1	-
Total number of studies ^a	15	47	3
Summary measures			
Incidence rates	-	27	-
Relative risk	-	10	-
Standardised mortality ratio	-	6	-
Frequency or count	15	5	3
Total number of studies ^b	15	48	3

^aSome studies reported more than one type of map, so the sum is not equal to $n = 62$. ^bOne study reported choropleth maps with two summary measures, so the sum is not equal to $n = 47$

3.6.3 Clustering/cluster detection studies

Table 3.4 summarises the characteristics of the clustering (global) or cluster detection (local) methods that were applied in 27 studies. Overall, the injury-cause categories investigated were road traffic accidents ($n = 15$), falls ($n = 6$), burns ($n = 2$), drowning ($n = 2$), occupational ($n = 1$) and poisoning ($n = 1$). In total, eight different clustering/cluster detection methods were used, with 13 studies using >1 method. Four methods (NNI, NnH, Moran's I , Geary's c) were applied to test for clustering and four methods (kernel density estimation [KDE], spatial scan statistics, LISA and Getis-Ord statistics) were applied to identify clusters or hot spots.

The most commonly applied method for aggregated data to test for spatial autocorrelation ($n = 13$ studies) was Moran's I (Moran, 1950) for which a value >1 indicates the presence of spatial autocorrelation. Widely applied hot spot analysis methods for aggregated data, namely the LISA and Getis-Ord statistics, were applied in four and five studies respectively (Chaney & Rojas-Guyler, 2016; Jerrett et al., 2010). Spatial scan statistics, the most common method in broader epidemiological studies (Auchincloss et al., 2012), were applied in four studies with rarer injury events such as poisoning, occupational or work-related injuries. The strength of spatial scan statistics includes their ability to adjust for confounding variables, population densities and, more importantly, multiple testing (Auchincloss et al., 2012; Kulldorff, 1997).

The most frequently used hot spot analysis method for point data ($n = 10$ studies) was KDE (considered to be a cluster detection method because of its ability to provide evidence of hot spots) which is mostly used for exploratory analysis of hot spots through a density map. The strength of KDE is that it provides evidence of hot spots in the visual form but the results of KDE methods are largely dependent on the bandwidth (search radius) parameter settings. (Fritz et al., 2013) This method was most commonly used in road traffic injuries ($n = 7$) followed by falls ($n = 2$) and drowning ($n = 1$). A commonly used clustering method for point data was NnH ($n = 4$), which determines clusters as standard deviational ellipses based on model parameters such as the specified threshold distance and minimum number of points to be included.

Table 3.4: Applied cluster detection methods according to spatial resolution and global/local estimation (n = 27 studies)

Method	Spatial resolution	Global/Total local	Injury category studies ^a (number of studies)	References
Kernel density estimation	point	local	10	Road traffic (n = 7) Falls (n = 2) Drowning (n = 1) (Cinnamon et al., 2011; Dai et al., 2013; Lai et al., 2009b; Lai et al., 2011; Lawrence et al., 2015; Morency and Cloutier 2006; Nagata et al., 2011; Schuurman et al., 2009;
Nearest neighbour hierarchical	point	global	4	Falls (n = 3) Drowning (n = 1) (Lai et al., 2009a; Lai et al., 2009b; Lai et al., 2011; Shenoi et al., 2015)
Nearest neighbour index	point	global	1	Road traffic (n = 1) (Nunn and Newby 2015)
Spatial scan statistics	point or areal	local	4	Falls (n = 2) Occupational (n = 1) Poisoning (n = 1) (Dey et al., 2010; Forst et al., 2015; Nkhoma et al., 2004; Yiannakoulis et al., 2003)
Moran's <i>I</i>	areal	global	13	Road traffic (n = 8) Falls (n = 1) Burns (n = 2) (de Pina et al., 2008; Erdogan 2009; Forst et al., 2015; Goltsman et al., 2014; Heng et al., 2014)
Geary's <i>c</i>	areal	global	2	Road traffic (n = 2) (Erdogan 2009; Lassarre and Thomas 2005)
Local indicators of spatial association	areal	local	5	Road traffic (n = 3) Drowning (n = 1) Falls (n = 1) (Dai et al., 2013; de Pina et al., 2008; Erdogan 2009; Nunes and Nascimento 2012; Nunn and Newby 2015)
Getis-Ord statistics	areal	local	4	Road traffic (n = 3) Burn (n = 1) (Erdogan 2009; Goltsman et al., 2014; Slaughter et al., 2014; Statter et al., 2011)

Total number of studies by injury category is not equal to (n = 27) because some studies applied more than one method in a single study.

3.6.4 Ecological studies

Three studies applied spatial regression methods to address aetiological questions. Spatial autoregressive models based on CAR ($n = 1$) and GWR ($n = 2$) frequentist approaches were applied to investigate social and environmental factors associated with road traffic mortality (Erdogan, 2009) and drownings (Dai et al., 2013; Shenoi et al., 2015). One of the drowning studies (Shenoi et al., 2015) applied a CAR spatial regression model to estimate the influence of sociodemographic and environmental variables (e.g., ethnicity, number of pools by single family and multi-family buildings) on the number of childhood swimming pool submersions. Similarly, GWR was applied in another study (Dai et al., 2013) to investigate the influence of social and physical characteristics (e.g., housing density, number of pools, open water bodies, median income) and drowning densities. The road traffic mortality study (Erdogan, 2009) applied GWR to investigate relationships between neighbourhood characteristics (e.g., length of roads, number of different types of vehicles) and death rates. The common rationale behind the use of spatial regression methods is to minimise the effect of spatial autocorrelation, as was illustrated by the included studies. A particular advantage of the GWR approach is that it is a local regression technique that allows aetiological relationships to vary from location to location, making it easier to interpret the results (Brunsdon et al., 1998).

3.7 Discussion

Geospatial methods are valuable for understanding injury outcomes because they can be used to recognise patterns of occurrence, identify priority areas for prevention measures and provide more accurate modelling of clustered data that is inherently correlated (Cromley & McLafferty, 2011; Ostfeld et al., 2005). While the benefits of geospatial methods have been widely known in broader public health applications for disease surveillance and data exploration in a spatial context (Auchincloss et al., 2012; Martinez et al., 2016; Rezaeian et al., 2007), this review shows that their use in the context of investigating unintentional injuries has been far less common.

Road traffic injuries were the most common category of injury causes investigated through geospatial methods. A possible reason for this could be the long-standing and well-managed injury surveillance systems for road traffic injuries that routinely collect data on the precise location of injury (e.g., specific road intersections). In addition, because there is a well-

recognised and significant public health burden from these injuries, especially for fatal cases, they have long been a high priority for injury data systems development and prevention (Ameratunga et al., 2006). Outside road traffic injuries, the use of geospatial methods has been more limited, mainly used in research of falls, burns and drowning injuries. This might be because of low counts of these injuries in a spatial context. There were some injury-cause categories that were notable for their absence in the published spatial epidemiology injury studies, including injuries associated with sport and recreation, an area that could be expanded through future research.

Over the past 15 years, there appears to have been an increasing application of geospatial methods for investigating unintentional injuries, demonstrated by the growing number of published studies using these methods, particularly since 2008. This is likely due to recent advancements in geospatial methods and the development of GIS, which has now made it possible to capture, store, manipulate, analyse, manage and present all types of spatial or geographical data (Fotheringham & Rogerson, 2013). It may also reflect the increased availability of routinely collected injury and determinant data that includes a spatial reference, as is now common from government and private organisations.

This review has demonstrated that mapping has been by far the most common spatial analysis approach adopted in injury epidemiological studies. Maps offer the advantage of presenting a clear visual representation of data showing regional or spatial variation in burden or injury risk (Martinez et al., 2016). Maps of standardised mortality ratios, relative risks or other similar statistical measures presented in the reviewed literature are useful for describing the spatial pattern of injury risk. However, basic mapping approaches may misrepresent spatial patterns because estimated standardised mortality ratios or other similar statistical measures do not take into account varying population sizes resulting in apparently large standardised mortality ratios in areas with small populations (Clayton & Kaldor, 1987; Lawson et al., 2000). To some extent, this problem can be addressed by applying smoothing models to the risk estimates that take the overall distribution of rates into account (Rezaeian et al., 2007). Widely accepted models such as the empirical Bayes (Clayton & Kaldor, 1987) and BYM (Besag et al., 1991) methods, were applied in very few of the included studies that involved small geographic areas with few cases (de Pina et al., 2008; DiMaggio, 2015; Heng et al., 2015; Lassarre & Thomas, 2005; Silva et al., 2011; Yiannakoulis et al., 2003).

It is fundamentally important that injury epidemiological studies begin to define spatial patterns statistically to determine whether observed clustering patterns occur by chance, or if there are statistically significant clusters that require further investigation (Pfeiffer et al., 2008). Many clustering/cluster detection methods have been developed over the past two decades based on different statistical approaches such as distance based, nearest neighbour, and scanning local rates for point and aggregated data (Auchincloss et al., 2012; Fritz et al., 2013). Our review identified that, in the context of unintentional injury research, very few clustering methods have been applied. Nonetheless, it is evident that the application of these methods has increased over the last eight years, mostly for road traffic injuries, but also falls and drowning. The statistical method regarded as having the best statistical power Tango's maximised excess events tests (Pfeiffer et al., 2008) has yet to be applied in the context of unintentional injuries. Compared to their application in broader public health studies, other methods such as K-functions and spatial scan statistics were also not common in injury studies.

There were differences apparent in the choice of geospatial methods for clustering/cluster detection in unintentional injury studies when compared to broader public health research, suggesting that unintentional injuries might be different in terms of their spatial contexts and, hence, need to be treated differently. It is beyond the scope of this particular review to assess this more formally, but it is certainly worthy of future research attention. There are no established guidelines to suggest which method is most appropriate for what type of injury data. Largely, it appears the choice of method is dependent on what has been readily integrated into common GIS packages. Each clustering/cluster detection method will produce a different result for the same dataset and that result will also vary based on parameter settings (Fritz et al., 2013). This means that identifying the appropriate method along with parameter settings for a particular dataset is challenging and requires multiple testing. Further research in this area would be a valuable contribution.

Health outcome data routinely collected by private and government agencies is often only available as aggregated summaries for well-defined geographic areas. In such cases, spatial inferences can be made at the aggregated level in relation to socio-economic and environmental risk factors for clues to aetiology (Beale et al., 2008). The increasing availability of routinely collected injury data in the form of aggregated summaries lends itself to potential opportunities for ecological studies (Beale et al., 2008). Statistical challenges for

this type of analysis include considering variability and potential error in rates, due to unequal population distributions and spatial autocorrelation (Elliot et al., 2000). The included studies that applied spatial regression techniques demonstrated how these methods can help to address statistical challenges associated with aggregated data by geographical regions (Dai et al., 2013; Erdogan, 2009; Shenoi et al., 2015). These studies also analysed a diverse range of factors (e.g., neighbourhood, environmental characteristics) which may not be possible to assess at an individual level.

Geospatial methods play an important role in understanding the influence of complex social environments on injury outcomes that will help to develop population level injury prevention strategies (Bell & Schuurman, 2010). In addition, they can help to identify which populations/sub-groups are consistently at greater (or lower) risk to inform the targeting of prevention efforts in those areas. This review has demonstrated that there is a move towards the use of more sophisticated geospatial methods from more traditional perspectives with the increasing availability in health and determinant data and also advances in GIS and other technologies. Continued advancement in this area would be well served by a detailed review of the quality of the geospatial methods currently adopted in injury epidemiological studies.

3.8 Limitations of this Review

A large number of the considered studies in the initial data selection phase investigated crash, collision or accident data without referring specifically to any injury incidence data. Some of these studies also appeared to have used the terms crash/collision/accident and injury interchangeably. This made it challenging to identify the studies that investigated injury data specifically. To address this, decisions to exclude a study were made only after agreement by two authors to help reduce the potential of excluding a publication in error.

In the reviewed literature, different terms were used to describe the application of geospatial methods in epidemiological studies (e.g., spatial epidemiology, spatial analysis, geographical variation, mapping, and geographical epidemiology). There is a possibility that some relevant keywords (e.g., space-time) were missed in the search strategy because of the multidisciplinary nature of this area and the use of many colloquial words by those who work in the area. Moreover, it is possible that searching of other databases, such as the transport research international documentation, may have identified some additional relevant papers. However, given the extensive study selection process the studies identified are likely to be a

highly representative sample of papers published in this area. If papers were missed, they are most likely from the category 1 studies (i.e., mapping of descriptive data), with no clear methodology indicating application of spatial methods. There is less likelihood that a study from category 2 or 3 (cluster or ecological methods) will have been missed, as authors of those studies would likely use the more familiar terminology in formal publications. Therefore, the major findings are unlikely to be influenced by any missed publications.

It should be noted that although we have categorised the studies into three distinct categories of spatial epidemiological approaches, this was to simplify the presentation of these results and understanding by a non-technical audience. In reality, these categories occur more along a continuous process rather than as discrete steps (Colantonio et al., 2011; Elliott & Wartenberg, 2004; Lawson et al., 2016). Many studies used multiple categories and methods and the boundaries between them were not always clear. For example, the most comprehensive studies began by mapping raw data, further explored the data using one or more cluster detection methods and then applied one or more spatial regression methods to understand the relationship with predictor variables (Dai et al., 2013; Shenoi et al., 2015).

The aim of this review has been to provide an overview of the types of geospatial methods applied to unintentional injury epidemiological studies. This study does not provide detail of the analytical processes or steps involved in cluster detection or the spatial regression methods identified. The interested reader is advised to consult key references for specific methods that have been presented throughout the paper (including Anselin, 1995; Brunsdon et al., 1998; Fritz et al., 2013; Getis and Ord, 1992; Kulldorff, 1997; Marshall, 1991).

3.9 Conclusions

This review has demonstrated that the application of geospatial methods to investigations of unintentional injuries has increased over recent years, but is still relatively uncommon. Most studies applying geospatial methods have focused on road traffic injuries. However, other injury-cause categories, particularly falls and burns, have also started to make use of geospatial methods in recent years. Mapping was the most commonly used approach for visual display of injury incidence rates. Where applied, cluster detection methods have identified statistically significant spatial dependency within the injury data under investigation. In such cases, the use of spatial regression techniques are needed to minimise the effect of spatial autocorrelation. Geospatial methods are rapidly emerging as an accessible

tool for injury researchers to better understand complex injury aetiology. However, to date, few authors have made use of their full potential in the major injury-cause categories.

3.10 Summary

There is increased interest in the application of the spatial epidemiological approach in unintentional injury epidemiological studies as demonstrated by the findings of this study. However, the findings highlighted that the application of the spatial epidemiological approach is limited in sport/leisure injury research. Of the three themes, mapping is the most commonly used, followed by cluster analysis and ecological analysis in injury-cause categories such as road traffic injuries, falls, drownings and burns. The purpose of mapping and cluster analysis is to describe the geographical variation and identify the priority areas for injury prevention efforts. The study also highlighted the importance of spatial epidemiological approach in injury research because most of the studies demonstrated that injuries are spatially dependent because of the influence of spatially linked environmental or contextual neighbourhood factors on the spatial pattern of injury occurrence. Hence, spatial regression methods need to be considered in ecological analysis because these methods factor in the spatial dependency that exists within the injury data.

A range of methods identified under each theme were summarised to provide an overview of methods commonly used in each theme. The common methods were different from those used in broader public health spatial epidemiological studies due to the unique nature of injury. This fundamental understanding will help identify appropriate methods for the spatial epidemiological investigation of sport/leisure injuries.

This study demonstrated that there is a lack of research in spatial epidemiological investigation of sport/leisure injuries. Therefore, the rest of this thesis will focus on spatial epidemiological investigation of sport/leisure injuries to address this major gap in the existing literature.

Chapter 4: Overview of the Data Used in this Thesis

4.1 Introduction

The previous chapter clearly shows a gap in the literature; there are no studies that have investigated sport/leisure injuries from a geographical perspective using geospatial methods. This thesis aims to address this gap by undertaking the first detailed spatial epidemiological investigation of sport/leisure injuries in Victoria.

The first step to achieve this is to identify and obtain sport/leisure injury datasets that have large geographical coverage, address population-level metrics and contain a variable that references a geographical location on earth. Therefore, to provide a greater understanding of the sport/leisure injury dataset used in this thesis, this chapter describes the source, characteristics and spatial dimension of the sport/leisure injury datasets. Additionally, this chapter also presents statewide sport/leisure injury hospitalisation rates by different variables available within the datasets to describe the extent of the sport/leisure injury problem in Victoria. The spatial characteristics of Victoria described in this chapter are used in the later chapters of this thesis.

4.2 Potential Sport/Leisure Injury Data Sources

There is no dedicated statewide sport/leisure injury surveillance system in Victoria. Therefore, sport/leisure injury data must be identified from existing sources of routinely collected data, such as hospitals, insurance or coronial records (Finch, Boufous & Dennis, 2006; Finch et al., 2014; Flood & Harrison, 2006; Gabbe et al., 2005; Otago & Peake, 2007). Additionally, sport/leisure injury data can be identified from specific studies aimed at capturing sport/leisure injury information in specific populations and activities using a variety of methods, such as surveys, interviews and electronic methods (e.g., short message service [SMS]) (Ekegren, Gabbe & Finch, 2014; Fortington, Donaldson & Finch, 2017; Verhagen, Collard, Paw & Van Mechelen, 2009).

The sports injury pyramid (see Figure 4.1) shows where treatment options for sport/leisure injuries are offered in the health system by different medical professionals (Finch, Ozanne-Smith & Williams, 1995). The sports injury pyramid suggests that the frequency of sport/leisure injuries decreases as the severity of the injury increases. In other words, the most

severe injuries, including death, occur rarely, while minor injuries occur frequently. This means that there is potentially more data for less-severe sport/leisure injuries treated at places such as medical clinics, physiotherapists and general practitioners (GPs) (Cassell et al., 2003). In contrast, there is potentially less data for injuries treated in hospitals, which only treat the most severe, major injuries that require immediate medical attention or hospital admission.



Figure 4.1: Sports injury pyramid-different levels of treatment sources of sport/leisure injury

Adapted from (Finch et al., 1995)

As noted earlier, there is no centralised repository of injury data for Victoria. However, theoretically, sport/leisure injury data are available at each level of treatment sources. Data that reports injuries at lower levels of the injury pyramid tend to be collected for specific studies. Often these will only cover a small geographic area, such as one medical/physiotherapy clinic (Cassell et al., 2003), or they are designed to capture injuries in a specific population, such as female Australian footballers (Fortington et al., 2017). Such studies use different injury definitions and data collection methods and there is no standard to the injury coding systems used across different studies. Hence, the data obtained through these systems or studies cannot be compared or merged with other available datasets. Therefore, injury data from lower levels of the pyramid tend not to be comparable across

studies, nor can they be merged into a single dataset. Accordingly, these data would not be suitable for the aim of this PhD thesis.

Moving further up the pyramid, each death or hospitalisation case is classified according to the WHO's International Classification of Diseases 10 Australian Modification (ICD-10-AM) coding system. Therefore, the hospitalisation cases and deaths collected in different locations can be merged into a single dataset covering large geographical areas, such as a state or country. In Victoria, routinely collected hospital admission data are centrally collected from all public and private hospitals and managed in a single dataset. Injuries that are treated in the emergency department are classified using text narratives, and further, not all public and private hospitals in Victoria have emergency facilities; as such, only admissions data can be utilised for this thesis, not ED data (Finch et al., 2014).

Previously, hospital data have mainly been analysed using standard statistical methods that have not given consideration to geospatial patterns that may exist within the data. Most commonly, results have been presented in the form of graphs, charts and tables. Along with the limitations of presenting data using the traditional methods described above, there are also some important components of the hospital data that are currently being under-utilised. For example, the hospital admissions dataset contains data on the residence of the injured person. This has rarely been considered in published reports of hospital data and when it has, it has only been used to describe the differences in sports injury incidence in rural and metro areas (Finch & Boufous, 2009). This geographical component of hospital data is the key data used for this PhD and so the work in this thesis presents data that has been underutilised in previous research.

4.3 Sport and Leisure Injury Data Source

The non-identifiable data of hospital admissions from all public and private hospitals of Victoria for injury and poisoning are held by the Victorian Injury Surveillance Unit (VISU) in the Victorian Admitted Episodes Dataset (VAED). The data are supplied to VISU by the Department of Health and Human Services (DHHS) for analysis, interpretation and dissemination for research purposes. The hospital injury data are coded using the ICD-10-AM coding system (NCCS, 2002). The ICD-10-AM provides a list of disease and injury and accompanying index to assist clinical coders; clinicians ensure that allocated disease and injury categories and associated indexes are consistent and appropriate in Australian clinical

practice. The reporting of injury according to the ICD-10-AM allows identification of cases of injury during participation in sport/leisure activities.

The sport/leisure injury data used in this thesis are extracted from hospital admission data. Relevant cases were identified on the basis that they had an activity code indicating that the person was involved in sport/leisure activity when they sustained the injury. However, there is a possibility that information about the activity at the time of injury could be missing or miscoded in hospital data because of insufficient detail provided at the time of reporting in the hospital.

4.3.1 Data acquisition

To obtain the data for this research, a request to VISU was made by the author of this thesis using VISU's standard online data request form (VISU, 2015). The number of sport/leisure injury hospitalisations by the categories of demographic and injury characteristics for each LGA of Victoria were obtained. LGAs are defined and maintained by the territory and local government department of each state (ABS, 2016). Normally, to protect privacy, cell counts that are smaller than 5 are suppressed and presented as a * instead of a number between 1-4. There was a possibility that many small counts for sports/leisure injuries by LGA would be suppressed, particularly once separated by different variables such as sex and age groups. For the geospatial analysis in this PhD, these small values are important. For example, it is possible that even when the hospital admission count is small in a given geographical area, the incidence rate may be higher and significant due to a small population in the given geographical area compared to geographical areas with high injury counts. For this reason, a special request was made to release data that included small cell counts (<5).

VISU does not have the authority to release small counts of sport/leisure injury hospitalisations (< 5) without permission from DHHS. Therefore, VISU forwarded the data request to DHHS for approval. Once VISU received approval from DHHS, a condition of release form was signed that indicated the rules and regulations to release findings derived from that dataset. Subsequently, the sport/leisure injury hospitalisation data were extracted from the VAED by VISU, including data with small cell counts by requested variables and provided in Excel format for analysis.

The total number of injuries in each LGA is based on the place of residence of the injured person rather than where the injury took place. The reason for using place of residence was,

first, the actual injury location was not available. Second, the aim was to investigate the influence of social and demographic characteristics of the area where the injured person lives.

4.3.2 Ethics approval

Ethical approval to analyse the sport/leisure injury hospitalisation data was obtained through Federation University Human Ethics Research Committee (HREC approval number: C15-018). Since the data were aggregated from non-identifiable unit records, individual consent for the routine collection of hospital admissions data is not required under legislation. The results were presented using the National Health and Medical Research Council (NHRMC) epidemiological reporting guidelines (NHMRC, 2007).

4.3.3 Case selection

The sport/leisure injury hospitalisation cases were selected based on the following inclusion criteria:

1. year of admission: 1 January 2005–31 December 2014, inclusive
2. if the principal diagnosis was an injury (S00-T75 or T79, ICD 10 AM code) sustained in the community. Non-community injuries are, for example, injuries sustained due to complication of injury or treatment, which are not relevant for this study because such injuries are not caused by external factors
3. if the first listed activity in the 40 diagnosis codes was in the range U50–U72. The codes (U50–U72) define that the person was injured when engaged in sport or leisure activity. Within this range of codes, over 200 activity codes were defined for identifying the specific type of sport and leisure activity. The U50–U71 codes define sports types (e.g., team ball sports [U50], team bat or stick sports [U51] and team water sports [U52]). Within each sports type, there are subcategories or individual sports. For example, within team ball sports there are subcategories such as football and netball. The football category includes Australian Football and soccer. U72 defines leisure activity that includes hobby activities (e.g., unorganised dance activities and gardening) and participation in activities of voluntary organisations.

Hospital admission cases were excluded if they were the result of a transfer from another hospital or due to a statistical separation (a change of care type) within the same hospital. The exclusion of these cases was undertaken to reduce the likelihood of a single injury is being

repeated multiple times in the extracted data. Sport/leisure injury hospitalisation cases from unincorporated areas and unknown and interstate cases were excluded from all analysis. The unincorporated areas such as ski resorts are not governed by their own local municipal corporation; this limits the availability of socio-economic data and other health indicators relating to those areas. They also cover a large geographical area with very small populations. Unknown and interstate cases do not have an actual geographical location in Victoria, and so could also not be used in the geospatial analysis.

4.3.4 Data variables

The sport/leisure injury hospitalisation data were obtained by categories of selected demographic and injury characteristics, as well as injury outcomes. Characteristics were selected based on their availability in the VAED database, their importance in terms of understanding regional variation and their common application as characteristics analysed in previous studies. The common characteristics analysed in national and statewide reports in non-spatial format were demographic characteristics such as age and sex, as well as associated factors such as place of occurrence and specific activity (Boufous, Dennis & Finch, 2006; Cassell et al., 2012; Kreisfeld et al., 2014). Injury-outcome variables were injury type, body region injured and length of stay in hospital. Sections 4.3.4.1–4.3.4.6 provide further detail on the selected variables used in this study.

4.3.4.1 *Sex*

- male
- female.

4.3.4.2 *Age*

Age was categorised into five-year groups (0–4, 5–9, 10–14, 15–19 ... 80–84, 85+). The five-year groups are further grouped into 0–14, 15–24, 25–44, 45–64 and over 65 years because this age grouping corresponds to a different levels of sport/leisure participation such as junior and senior levels.

4.3.4.3 *Activity*

Activity defines the sport or leisure activity, such as Australian Football, basketball, soccer or cricket, in which the individual was engaged when the injury occurred. The number of

injuries associated with each sport may not be homogeneously distributed by geographic regions. Therefore, it is important to describe their geographical pattern to identify regions with high and low burden, based on the specific activities. In addition, a selection of activity-specific injury hospitalisations is presented and explored by demographic characteristics and injury outcomes.

4.3.4.4 *Place of occurrence*

Place of occurrence defines the type of place where the injury occurred (see Table 4.1). This characteristic was included to investigate the geographical pattern of injuries that occurred in specific places. For example, geographical regions with a high rate of injuries occurring at home may be different than the high rates of injuries at sports and athletics areas. Therefore, the analysis will help describe geographical regions of high and low burden based on place of occurrence categories.

Table 4.1: Place categories (ICD-10-AM codes) in the sport/leisure injury hospitalisation data

ICD-10-AM Codes	Place of Occurrences
Y92.0	Home
Y92.1	Residential institutions
Y92.2	School, public buildings
Y92.3	Sports and athletic areas
Y92.4	Road, street and highways
Y92.5	Trade and service areas
Y92.6	Industrial and construction areas
Y92.7	Farms
Y92.8	Other specified places
Y92.9	Unspecified places

4.3.4.5 *Injury type*

Injury type defines the type of injury sustained as a result of sport/leisure injury based on the primary diagnosis code (see Table 4.2). This characteristic was included to investigate the geographical pattern according to the type of injury. This may provide evidence for policymakers to prioritise the need of health professionals in these areas.

Table 4.2: Injury types in the sport/leisure injury hospitalisation data

Fracture	Injury to nerves and spinal cord
Dislocation, sprain and strain	Systemic-poisoning/toxic effects
Open wound	Burns
Other and unspecified injury	Traumatic amputation
Injury to muscle and tendon	Injury to blood vessels
Intracranial injury	Eye injury—excluding foreign body
Superficial injury	Foreign body
Injury to internal organs	Crushing injury
Other effects of external cause/complications/late effects	

4.3.4.6 *Body region*

Body region defines the body region injured as a result of sport/leisure injury based on the primary diagnosis code (see Table 4.3). This characteristic was included to describe geographical pattern according to body region injured.

Table 4.3: Body region categories in the sport/leisure injury hospitalisation data

Abdomen, lower back, lumbar spine and pelvis	Foreign body—eye
Ankle and foot	Foreign body—genitourinary tract
Body region not relevant	Foreign body—respiratory tract
Burn—eye	Head
Burn—head and neck	Hip and thigh
Burn—lower limb	Knee and lower leg
Burn—other internal organs	Multiple body regions
Burn—respiratory tract	Neck
Burn—trunk	Shoulder and upper arm
Burn—upper limb	Thorax
Elbow and forearm	Unspecified body region
Foreign body—alimentary tract	Wrist and hand
Foreign body—ear	

4.3.4.7 *Length of stay in hospital*

Length of stay in hospital describes the time required for treatment in hospital as a result of a sport/leisure injury. This characteristic was included to describe the geographical pattern by the length of stay in the hospital. The length of stay was divided into four categories: fewer than two days, 2–7 days, 8–30 days and 31+ days. This variable also indicates the severity of

the injury. For example, an injury that requires a hospital stay of over 30 days is a more severe injury than an injury that requires a hospital stay of fewer than two days.

4.4 Geographical Boundaries

The Australian Statistical Geography Standard (ASGS) provides a framework of statistical areas used by the ABS and other organisations to enable the publication of statistics that are comparable and spatially integrated (ABS, 2011a). The ASGS framework is used to provide a consistent method for the ABS and other agencies to collect and report region-specific statistics (ABS, 2011a). The ASGS is divided into two broad categories: (i) ABS structures (ii) non-ABS structures. The ABS structures defined and maintained by the ABS include Statistical Area Level 1 (SA1) and Statistical Area Level 2 (SA2). Non-ABS structures defined and maintained by other organisations include LGAs.

The 2011 LGA boundaries were obtained from the ABS in Environmental Systems Research Institute (ESRI) shapefile format (ABS, 2016). This contains the geometry of each Victorian LGA along with information about LGAs, such as the LGA code and name. In the obtained shapefile, Victoria is divided into 81 LGAs. This includes unincorporated areas of Victoria (LGA code 29339) and no usual address (LGA code 29499). A map showing the LGAs of Victoria is presented in Figure 4.2.



Figure 4.2: LGAs of Victoria

Source: (ABS, 2016)

4.5 Neighbourhood Characteristics

The neighbourhood usually represents a small geographical area. The characteristics of the neighbourhood can be an important determinant for injury outcome (Cubbin, LeClere & Smith, 2000a; Simpson, Janssen, Craig & Pickett, 2005). In this thesis, LGA is considered as the neighbourhood in later chapters. The neighbourhood characteristics of remoteness and SES are used in this thesis.

4.5.1 Accessibility/Remoteness Index of Australia

The Accessibility/Remoteness Index of Australia (ARIA+) is the standard ABS-endorsed measure of remoteness (ABS, 2011b; Glover & Tennant, 2003). The ARIA+ is an index of the accessibility of places to service centres, where population localities are given a score (0–15) based on the road distance to service towns of different sizes (ABS, 2011b). The remoteness categorisation of each Victorian LGA as of 2011 was obtained from DHHS (DHHS, 2015). The remoteness categories based on ARIA+ scores are (i) major cities (0–0.2), (ii) inner regional (0.3 <= 2.4), (iii) outer regional (2.5 <= 5.92), (iv) remote (5.93 <= 10.53), and (v) very remote (> 10.54). Of the six Australian states, Victoria is the second most populous state with high-population density. Thus, Victoria only has three remoteness regions (see Figure 4.3).

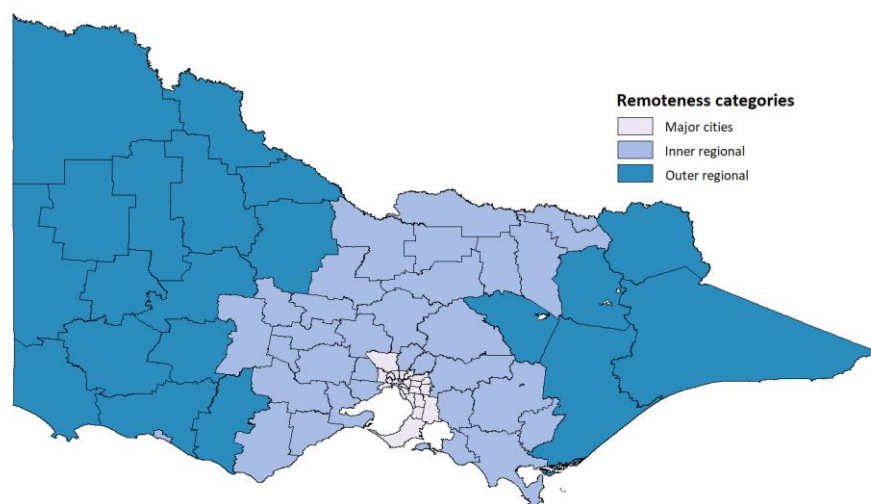


Figure 4.3: Remoteness regions of Victoria based on Accessibility Remoteness Index of Australia

4.5.2 Socio-Economic Indexes for Areas

The Socio-Economic Indexes for Areas (SEIFA) is a product developed by the ABS that ranks neighbourhoods (LGA) in Australia according to relative socio-economic advantage and disadvantage (ABS, 2011d). It uses five-yearly census information to rank each Australian LGA in this way (ABS, 2011d). Of the four SEIFA indexes, the Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) was used in this thesis to define SES of the LGA. The IRSAD includes both relative advantage and disadvantage measures. For example, a low IRSAD score indicates a lack of advantage in general and a relatively greater disadvantage. IRSAD scores derived from the 2011 census of population and housing for each Victorian LGA were obtained from the ABS (ABS, 2011c). The IRSAD score of each LGA was divided into quintiles and named: (i) most advantaged (first quintile), (ii) advantaged (second quintile), (iii) middle SES (third quintile), (iv) disadvantaged (fourth quintile) and (v) most disadvantaged (fifth quintile). These are presented in Figure 4.4.

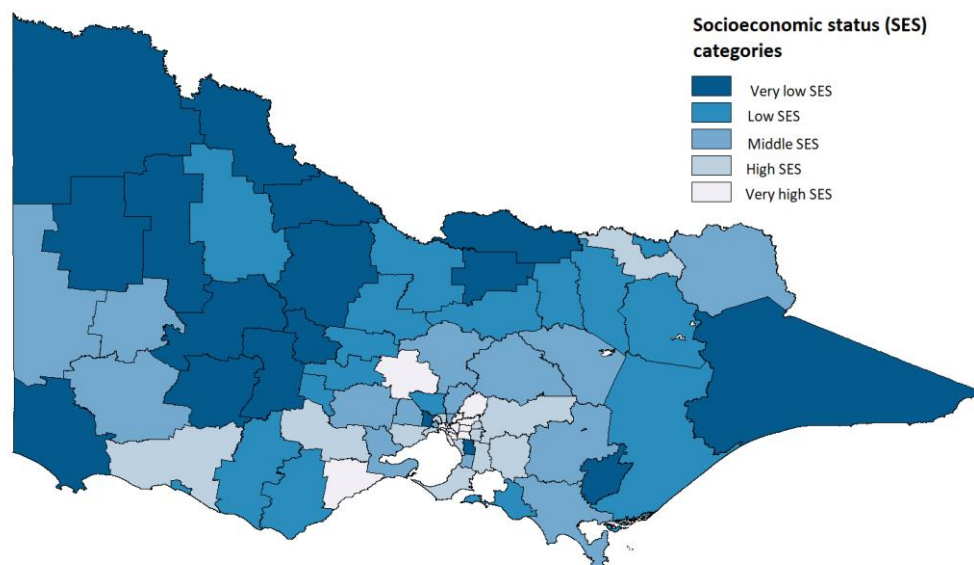


Figure 4.4: Socio-economic regions of Victoria based on IRSAD (2011)

4.6 Sport/Leisure Participation

The population at risk of sport/leisure injury comprises all those who participate in sport/leisure activities. It is important that to note that not all Victorians participate in sport/leisure activities. Participation can vary by sports, geographic units, age and gender. There is limited information available about sport/leisure participation at the population level.

Each financial year, the ABS conducts a Multi-Purpose Household Survey (MPHS) for people aged 15 years and over throughout Australia in which one of the topics relates to sport and leisure participation 12 months prior to the interview (ABS, 2007). Due to the unavailability of sport and leisure participation data at the LGA or postal areas (POA) level, statewide measures derived from the MPHS survey were used to measure sport/leisure activities participation in each LGA and POA. To obtain this figure, the following steps were followed.

Step 1: The 2011 population estimates by five-year age group and sex were extracted from the ABS (ABS, 2014). The 2011 population estimates were determined the most appropriate because neighbourhood characteristics such as SEIFA were derived from the 2011 census.

Step 2: The estimates of sport and recreation participation rates derived from the MPHS conducted in 2011–2012 and information on age and sex were extracted from the Participation in Sport and Physical Recreation, Australia report from the ABS (see Table 4.4). The age data were further grouped as per the injury data groups (see Table 4.5). Accordingly, the sport and leisure participation rates for most the common sports leading to hospitalisations (see Table 4.11) were also extracted (Table 4.6).

Table 4.4: Age and gender-specific sport and physical recreation participation rates derived from 2011–2012 MPHS (ABS, 2012)

Age Group (Years)	Participation Rate (%)		
	Males	Females	Persons
15–17	90.3	71	80.9
18–24	82.4	69.5	76.1
25–34	69.5	69.8	69.7
35–44	66.1	69.2	67.7
45–54	59.5	68	63.8
55–64	66.9	65.7	66.3
65 and over	54.3	47.5	50.7

Table 4.5: Age and gender-specific sport and physical recreation participation rates derived from 2011–2012 MPHS (ABS, 2012)

Age Group (Years)	Participation Rate (%)		
	Males	Females	Persons
15–24	86.4	70.3	78.5
25–44	67.8	69.5	68.7
45–64	63.2	66.85	65.05
65 and over	54.3	47.5	50.7
Average	70.6	66.7	68.8

Table 4.6: Sport-specific participation rates derived from 2011–2012 MPHS (ABS, 2012)

Sports	Participation Rate (%)
Australian Football	2.0
Basketball	3.2
Soccer	1.9
Cricket	2.0

Step 3: To calculate the sport/leisure participants in each LGA, the age- and gender-specific population of the LGAs were multiplied by the statewide age- and gender-specific participation rates. Since statewide participation rates are only available for people aged 15 years and over, the average participation rate was applied to the population aged below 15 years to provide a useable estimate. For example, Table 4.7 shows the process used in this thesis to calculate the sport/leisure participants of Victoria. Accordingly, a similar process was conducted to calculate the sport/leisure participants in each LGA.

Table 4.7: Number of sport/leisure participants in Victoria by age groups, based on the 2011–2012 MPHS

Age Group	Population		Participation Rate (%)		Estimated Sport/Leisure Participants		
	Male	Female	Male	Female	Male	Female	Persons
0–14	512,231	485,432	70.6	66.7	361,814	323,929	685,743
15–24	366,822	351,923	86.4	70.3	316,751	247,226	563,977
25–44	751,983	779,851	67.8	69.5	509,844	541,996	1,051,841
45–64	652,204	683,398	63.2	66.9	412,193	456,852	869,044
65+ years	344,189	416,775	54.3	47.5	186,895	197,968	384,863
Total	2,627,429	2,717,379			1,787,497	1,767,971	3,555,468

Step 4: Similar to the lack of availability of participation data for the geographic unit of analysis, sport-specific participation data are also not available. Therefore, an estimate from the 2011–2012 MPHS was used to calculate sport/leisure participants for the most common sports in Victoria (see Table 4.8).

Table 4.8: Number of participants in four sports in Victoria, based on the 2011–2012 MPHS

Sports	Participation Rate (%)	Total Population of Victoria	Estimated Sport/Leisure Participants
Australian Football	2.0	5,344,808	106,896
Basketball	3.2	5,344,808	171,034
Soccer	1.9	5,344,808	101,551
Cricket	2.0	5,344,808	106,896

4.7 Statewide Profile of Sport/Leisure Injury Hospitalisations

This section provides a statewide overview of sport/leisure injury hospitalisations in Victoria. The results presented in this section are used to identify the common categories of demographic and injury-outcome characteristics, which are further explored later in this thesis. Additionally, the statewide descriptive results in this section are compared with the region-specific statistics in later chapters.

4.7.1 Methods

The annual incidence rate per 100,000 participants is calculated as:

$$\text{Incidence rate} = \frac{\text{Number of injuries}}{\text{Sport and leisure participants}} \times 100,000$$

In this, the denominator (sport/leisure participants) is derived using the sports participation data from MPHS as described in Section 4.6. Ninety-five per cent confidence intervals (CI) (95% CI) for incidence rates were calculated assuming a Poisson distribution. The incidence rates and 95 per cent CI were calculated using R statistical software (R Core Team, 2013).

4.7.2 Results

During the 10-year period analysed, there were 104,271 sport/leisure injury hospitalisations in Victoria. This equates to a sport/leisure injury hospitalisation incidence rate of 293.3 (95% CI 291.5–295.1) per 100,000 participants/year (see Table 4.9).

4.7.2.1 Sex and age

The number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations by sex are presented in Table 4.9. The sport/leisure injury hospitalisations were more common in males than they were in females. Of all the sport/leisure injuries that led to hospital admission, 72.7 per cent were males at a rate of 424.1/ 100,000 participants/year.

Table 4.9: Number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations, by sex, Victoria, 2005–2014

Sex	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
Male	75,800	17,874,972	72.7%	424.1	421.0–427.1
Female	28,471	17,679,708	27.3%	161.0	159.2–162.9
Total	104,271	35,554,680	100.0%	293.3	291.5–295.1

The number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations by age groups is presented in Table 4.10. The rates by age groups ranged from a low of 144.9/100,000 participants in over 65-year-olds to a high of 519.6/100,000 participants/year in the 15–24 years age groups.

Table 4.10: Number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations, by age groups, Victoria, 2005–2014

Age Group	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
0–14	29,763	6,857,431	28.5%	434.0	429.1–439.0
15–24	29,306	5,639,767	28.1%	519.6	513.7–525.6
25–44	28,860	10,518,409	27.7%	274.4	271.2–277.6
45–64	10,765	8,690,445	10.3%	123.9	121.5–126.2
65+	5,577	3,848,628	5.3%	144.9	141.1–148.8

4.7.2.2 *Sport/leisure activity type*

Overall, 217 types of sport/leisure activities contributed to 104,271 hospitalisations. The number and rates per 100,000 participants/year for the five most common activity types are presented in Table 4.11. The activities are Australian Football, soccer, basketball and cricket. These activities accounted for 27.5 per cent of the total number of sport/leisure injury hospitalisations. Among those five, the highest injury rate (1,355.4/100,000 participants/year) was observed in Australian Football, while the lowest rate (243.9/100,000 participants/year) was observed in cricket. The other categories accounted for 72.5 per cent of total hospitalisations.

Table 4.11: Number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations for five most common activity types (ICD-10-AM), Victoria, 2005–2014

Activity	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
Australian Football	14,489	1,068,962	13.9%	1,355.4	1,333.4–1,377.7
Soccer	6,195	1,015,514	5.9%	610.0	594.9–625.4
Basketball	5,415	1,710,339	5.2%	316.6	308.2–325.2
Cricket	2607	1,068,962	2.5%	243.9	234.6–253.4

4.7.2.3 *Place of occurrence*

The number, proportion and rate per 100,000 participants/year of sport/leisure injury hospitalisations for the four most common places of occurrence are presented in Table 4.12. The place categories are ‘sports and athletic areas’, ‘school, public buildings’, ‘home’ and ‘road, street and highway’; 57.6 per cent of sport/leisure injury hospitalisations occurred in these places. The largest proportion (38.6 per cent) of sport/leisure injury hospitalisations occurred at sport and athletics areas (113.2/100,000 participants/year). Among those four, the smallest proportion (5.5 per cent) of sport/leisure injury hospitalisations occurred at trade and service areas (2.5/100,000 participants/year). Finally, 42.4 per cent of hospitalisations occurred at ‘other’ places (124.4/100,000 participants/year).

Table 4.12: Number, proportion and rates per 100,000 participants/year, of sport/leisure injury hospitalisations for five most common places of occurrences, Victoria, 2005–2014

Place of Occurrence	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
Sports and athletic areas	40,259	35,554,680	38.6%	113.2	112.1–114.3
Schools, public buildings	7,259	35,554,680	7.0%	20.4	19.9–20.9
Home	6,834	35,554,680	6.6%	19.2	18.8–19.7
Road, street and highway	5,687	35,554,680	5.5%	16.0	15.6–16.4
Others	44,232	35,554,680	42.4%	124.4	123.2–125.6

4.7.2.4 *Injury type*

The number, proportion and rate per 100,000 participants/year of sport/leisure injury hospitalisations for five the most common injury types are presented in Table 4.13. The injury types are ‘fracture’, ‘dislocation, sprain and strain’, ‘open wound’, ‘injury to muscle and tendon’ and ‘intracranial injury’ accounting for 86.3 per cent of total sport/leisure injury hospitalisations. The largest proportion (57.5 per cent) of sport/leisure injury hospitalisations

were fractures (168.5/100,000 participants/year). Among those five categories, the lowest proportion (4.6 per cent) of total sport/leisure injury hospitalisations were intracranial injuries (13.6/100,000 participants/year). The other 28 injury types combined only accounted for 12.6 per cent of total sport/leisure injury hospitalisations.

4.7.2.5 *Body region*

The number, proportion and rate per 100,000 participants/year of sport/leisure injury hospitalisations for the five most common body region categories are presented in Table 4.14. The body region categories are ‘knee and lower leg’, ‘elbow and forearm’, ‘head’, ‘wrist and hand’ and ‘shoulder and upper arm’, accounting for 82.2 per cent of total sport/leisure injury hospitalisations. The largest proportion (23.6 per cent) of total sport/leisure injury hospitalisations were knee and lower leg injuries (69.2/100,000 participants/year). Among those five body region categories, the lowest proportion (9.4 per cent) of total sport/leisure injury hospitalisations were shoulder and upper arm injuries (27.4/100,000 participants/year). The other 20 body region categories combined accounted for 17.2 per cent of total sport/leisure injury hospitalisations.

Table 4.13: Number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations for five most common types of injuries, Victoria, 2005–2014

Injury Type	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
Fracture	59,923	35,554,680	57.5%	168.5	167.2–169.9
Dislocation, sprain and strain	13,528	35,554,680	13.0%	38.0	37.4–38.7
Open wound	7,147	35,554,680	6.9%	20.1	19.6–20.6
Injury to muscle and tendon	5,690	35,554,680	5.5%	16.0	15.6–16.4
Intracranial injury	4,841	35,554,680	4.6%	13.6	13.2–14.0
Others	13,142	35,554,680	12.6%	37.0	36.3–37.6

Table 4.14: Number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations for five most common body region categories, Victoria, 2005–2014

Body Region	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
Knee and lower leg	24,587	35,554,680	23.6%	69.2	68.3–70.0
Elbow and forearm	18,957	35,554,680	18.2%	53.3	52.6–54.1
Head	17,117	35,554,680	16.4%	48.1	47.4–48.9
Wrist and hand	15,279	35,554,680	14.7%	43.0	42.3–43.7
Shoulder and upper arm	9,755	35,554,680	9.4%	27.4	26.9–28.0
Others	18,576	35,554,680	17.8%	52.2	51.5–53.0

4.7.2.6 *Length of stay*

The number, proportion and rate per 100,000 participants/year of sport/leisure injury hospitalisations by bed days are presented in Table 4.15. The days spent in hospital due to injury are grouped into < 2 days, 2–7 days, 8–30 days and 31+ days. The largest proportion (69.9 per cent) of total sport/leisure injury hospitalisations were for fewer than 2 days (205.1/100,000 participants/year). Only small proportion (0.2 per cent) of total sport/leisure injury hospitalisations were for over 31+ days.

Table 4.15: Number, proportion and rates per 100,000 participants/year of sport/leisure injury hospitalisations by bed days, Victoria, 2005–2014

Bed Days Grouped	Number of Hospitalisations 2005–2014	Sport/Leisure Participants 2005–2014	Proportion of all Cases	Sport/Leisure Injury Hospitalisation Incidence Rate per 100,000 Participants/Year	95% CI
< 2 days	72,914	35,554,680	69.9%	205.1	203.6–206.6
2–7 days	27,872	35,554,680	26.7%	78.4	77.5–79.3
8–30 days	3,309	35,554,680	3.2%	9.3	9–9.6.0
31+ days	176	35,554,680	0.2%	0.5	0.4–0.6

4.8 Conclusions

This chapter describes the source, characteristics and spatial dimension of the sport/leisure injury datasets. Further, it presents statewide hospital admission rates by different variables available within the datasets to describe the extent of the sport/leisure injury problem in Victoria. Out of the many potential sport/leisure injury data sources, the sport/leisure injury hospitalisation data were the most appropriate for the objective of this PhD research. An ethical approval was obtained from Federation University Australia prior to analysing the dataset.

The findings of this chapter suggested that injury hospitalisation rates were significantly higher in males than in females. The highest sport/leisure injury hospitalisation rate was observed in the 15–24 years group, while the lowest sport/leisure injury hospitalisation rate was recorded in the 45–64 years group. Australian Football had the highest rates of injury hospitalisations compared to other specific sports like basketball and soccer. More than one-third of sport/leisure injury hospitalisations occurred at sports and athletics areas. The largest proportion of hospitalisations were fractures. The most common body region injured was the knee and lower leg. Injured people were mostly required to stay in hospital for fewer than two days.

The findings suggest there is variation in sport/leisure injury incidence rates across different categories of demographic and injury-outcome characteristics. Therefore, it is likely that there might be significant geographic variation in the distribution of sport/leisure injury hospitalisation rates by categories of demographic variables and specific sports. It is important to understand geographical variation and identify priority areas for targeting injury prevention efforts. Therefore, the next two chapters will focus on describing and identifying priority areas in a geographical context.

Chapter 5: Geographical Mapping of Sport and Leisure Injury Hospitalisations

5.1 Introduction

As discussed in the thesis introduction, use of geospatial methods in injury or broader public health research is categorised into three application areas: mapping, clustering and ecological analysis. Geographical mapping is commonly used to describe the geographical pattern or trend of health outcomes including injuries (Chong & Mitchell, 2009; Colantonio et al., 2011; Goltsman et al., 2014; Singh et al., 2016). In the past decade, there has been an increasing application of geographical mapping in injury research due to the growing availability of spatially referenced injury datasets, geospatial methods and technologies (Auchincloss et al., 2012; Singh et al., 2016). In addition, with the capability of geospatial methods and technologies, it is now possible to generate more stable estimates for smaller and more detailed geographic areas to present these data in a more meaningful way (Chong & Mitchell, 2009; Lawson et al., 2000). Specifically, the mapping of injuries in a geospatial context helps policymakers, health service providers and the public assess the relative injury burden in different settings.

A geographical approach to public health is important because populations and communities live in areas with similar underlying characteristics such as physical, environmental, lifestyle and socio-economic characteristics (Craglia & Maheswaran, 2016). In general, larger geographic regions are divided into smaller regions based on similar underlying characteristics. For example, the traditional geographical classification based on remoteness and SES are rural/metropolitan and high-SES/low-SES regions. Studies that have investigated health outcomes by remoteness areas have shown that people living in rural areas have poorer health outcomes than people living in urban areas do (Finch & Boufous, 2009; Mitchell & Chong, 2010; Pong, DesMeules & Lagacé, 2009; Smith, Humphreys & Wilson, 2008). Therefore, when reporting injury incidences by geographical areas, it is important to highlight the injury risk by region. In a sport/leisure injury context, a limited number of studies have investigated injury rates across geographic and socio-economic regions using traditional approaches (Finch, Mahoney, Townsend & Zazryn, 2003; Finch & Boufous, 2009; Lam, 2005; Lower, 1996). These studies have reported higher injury

incidences in remote and regional areas compared to the burden borne by urban areas. There is increasing injury burden linked with increasing rurality but no association between socio-economic regions and sport/leisure injury hospitalisation rates (Finch & Boufous, 2009; Lam, 2005). These studies were conducted in NSW, Australia. There have been no studies in Victoria to date that have reported injury rates by region, categorised by remoteness, SES and local government boundaries. Additionally, no studies were found internationally that investigated geographical trends of sport/leisure injuries using geospatial methods (Singh et al., 2016). Therefore, the aim of this chapter is to examine the sport/leisure injury hospitalisation rates by socio-economic and remoteness categories and describe the geographical trend of sport/leisure injury hospitalisations using geospatial methods.

5.1 Methods

5.1.1 Rates by remoteness and socio-economic areas

As described in Chapter 4 (see Sections 4.5.1 and 4.5.2), Victoria is divided into three remoteness and five socio-economic regions. For each remoteness and socio-economic region, annual sport/leisure injury hospitalisation incidence rates per 100,000 participants/year were calculated as:

$$incidence\ rate = \frac{Number\ of\ injuries}{sport\ and\ leisure\ participants} \times 100,000$$

The numerator and denominator data are described in Chapter 4 (see Sections 4.4 and 4.6 respectively). The annual sport/leisure injury hospitalisation incidence rates were calculated for categories of demographic characteristics and activities (see Table 5.1).

Table 5.1: Annual sport/leisure injury hospitalisation incidence rates calculated for gender and age group categories and specific activities

Gender	Age Groups	Activity
Male	0–14 years	Australian Football
Female	15–24 years	Soccer
	25–44 years	Basketball
	45–64 years	Cricket
	Over 65 years	

The 95 per cent CIs were estimated using Poisson distribution. The estimated rates were presented in graphs and tables using R statistical software (R Core Team, 2013). Individual category comparisons were based on the reported CIs.

5.1.2 Rates by LGA

As explained in Chapter 4, there are 79 LGAs in Victoria, excluding unincorporated areas. When examining the injury rates by LGA, crude rates may be unreliable because of the relatively few cases observed in some areas with a small population (Lawson et al., 2000). Therefore, to produce reliable estimates, a statistical smoothing method was used to borrow strength from the overall distribution of the data (Lawson & Williams, 2001). One such method is empirical Bayes (EB) smoothing. This method is commonly used for smoothing geographic distribution of injury data (Singh et al., 2016). In this approach, the weighted average is computed between the crude rate of each LGA and the statewide average, with weights proportional to the underlying population at risk (Bailey & Gatrell, 1995). Using this technique, the rates of LGAs with a small population will be adjusted considerably, whereas the rates of LGAs with a large population will barely change.

Smoothing was conducted using the EB method available in GeoDa 1.8 (Anselin, Syabri & Kho, 2006). In this approach, injury cases of each LGA (see Section 4.4) formed the numerator and the estimated LGA-specific participation data (see Section 4.6) were the denominator. The LGA-specific rates were calculated by categories of demographic characteristics and activities.

Although estimating rates is crucial, it is also important to present the estimated values in a meaningful way. For this, the estimated values were presented in choropleth maps with a gradient of blue, with dark blue indicating high rates using the QGIS (QGIS Development Team, 2012). The smoothed rates were classified using the natural break (Jenks) method. This method seeks to group data so that variation within groups is minimised and variation between groups is maximised (De Smith et al., 2007).

5.2 Results

5.2.1 Overall sport/leisure injury hospitalisations

Figure 5.1 shows the sport/leisure injury hospitalisation rates per 100,000 participants/year for each of the remoteness and socio-economic categories of Victoria. Across remoteness categories, the sport/leisure injury hospitalisation rates ranged from a low of 272.5 per 100,000 participants/year (95% CI: 270.3–274.7) in major cities to a high of 371.9 per 100,000 participants/year (95% CI: 363.5–379.7) in outer regional areas. The estimated sport/leisure injury hospitalisation rates of each remoteness area were significantly different than the rates of other remoteness categories.

Across socio-economic categories, the sport/leisure injury hospitalisation rates ranged from a low of 251.5 per 100,000 participants/year (95% CI: 247.5–255.6) in the most disadvantaged areas to a high of 313.9 per 100,000 participants/year (95% CI: 309.7–318.1) in advantaged areas. The rate of sport/leisure injury hospitalisations was significantly lower in the most disadvantaged areas compared to other socio-economic categories of Victoria. Higher sport/leisure injury hospitalisation rates were observed in the most advantaged and advantaged categories than they were in other socio-economic categories.

A map depicting smoothed sport/leisure injury hospitalisation rates is presented in Figure 5.2. Higher sport/leisure injury hospitalisation rates were mostly observed in regional LGAs in western Victoria. The sport/leisure injury hospitalisation rates across LGAs ranged from a low of 80.6 per 100,000 participants/year to a high of 757.0 per 100,000 participants/year. The mean sport/leisure injury hospitalisation rate across LGA was 329.2. Standard deviation was 106.2 per 100,000 participants/year.

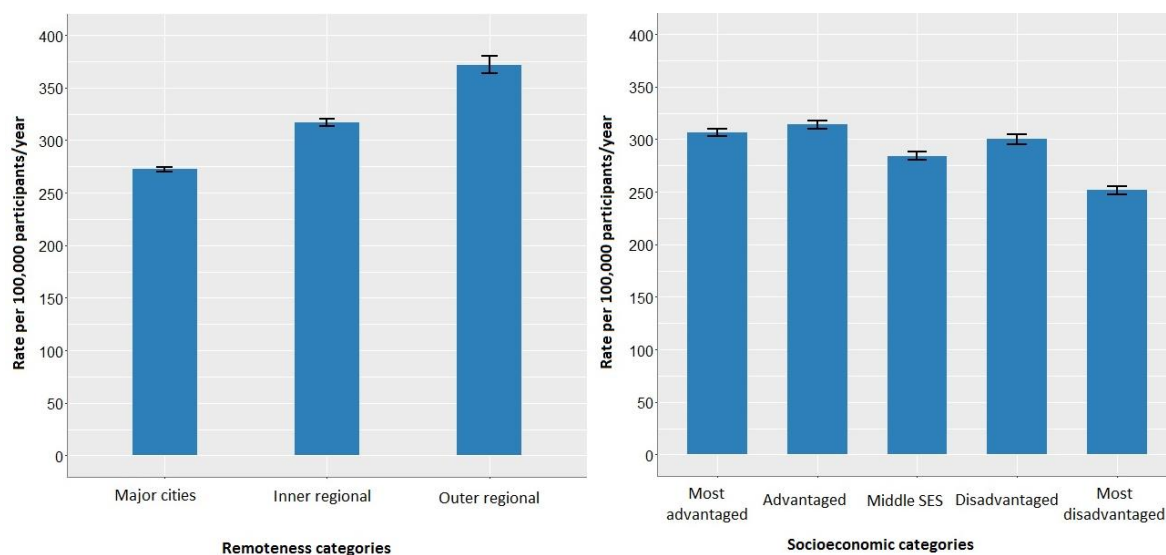


Figure 5.1: Sport/leisure injury hospitalisation rates per 100,000 participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

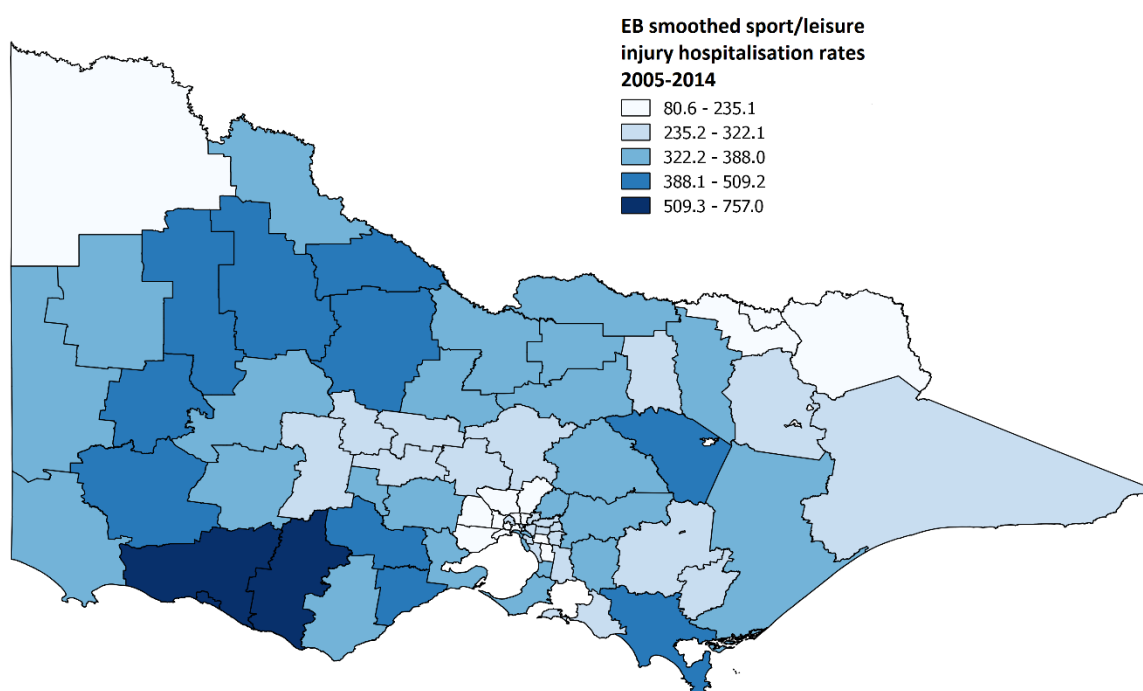


Figure 5.2: EB smoothed sport/leisure injury hospitalisation rates per 100,000 participants/year by LGAs of Victoria, 2005–2014

5.2.2 Sex

5.2.2.1 *Male sport/leisure injury hospitalisations*

Figure 5.3 depicts the male sport/leisure injury hospitalisation rates per 100,000 male participants/year for each of the remoteness and socio-economic categories of Victoria. Across remoteness categories, the male sport/leisure injury hospitalisation rates ranged from a low of 398.6 per male 100,000 participants/year (95% CI: 394.8–402.4) in major cities to a high of 514.8 per 100,000 male participants/year (95% CI: 501.5–528.3) in outer regional areas. The estimated male sport/leisure injury hospitalisation rates of each remoteness area were significantly different than the male sport/leisure injury hospitalisation rates of other remoteness areas.

Across socio-economic categories, the male sport/leisure injury hospitalisation rates ranged from a low of 366.6 per 100,000 male participants/year (95% CI: 359.8–373.4) in the most disadvantaged areas, to a high of 452.0 per 100,000 male participants/year (95 per cent CI: 445.0–459.1) in advantaged areas. The rate of male sport/leisure injury hospitalisations was significantly lower in most disadvantaged areas compared to the male sport/leisure injury hospitalisation rates of other socio-economic categories. Higher male sport/leisure injury hospitalisation rates were observed in the most advantaged and advantaged categories than in the male sport/leisure injury hospitalisation rates of other socio-economic categories.

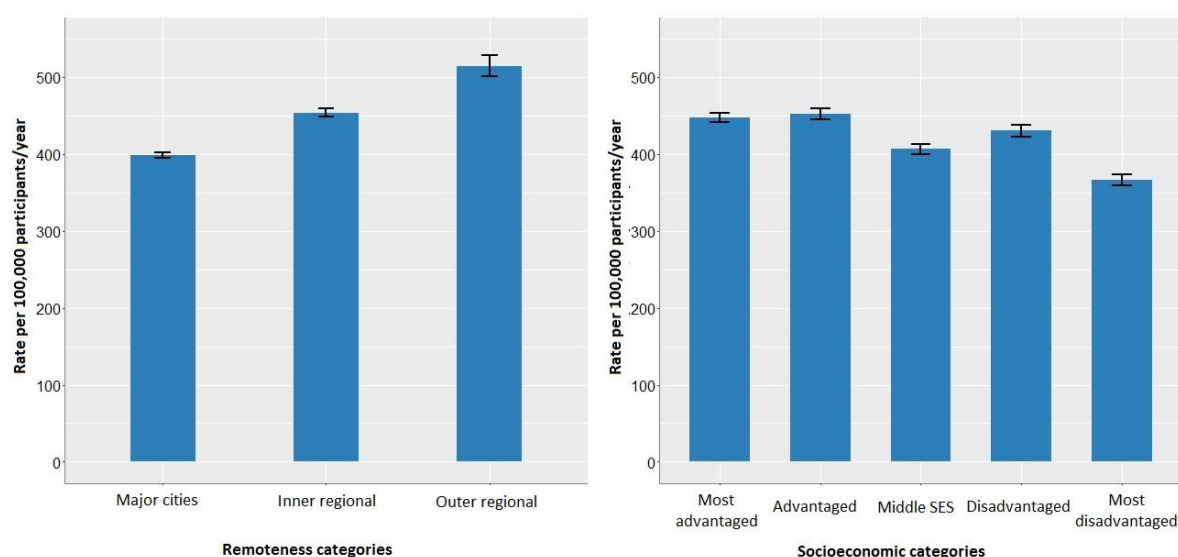


Figure 5.3: Sport/leisure male injury hospitalisation rates per 100,000 male participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

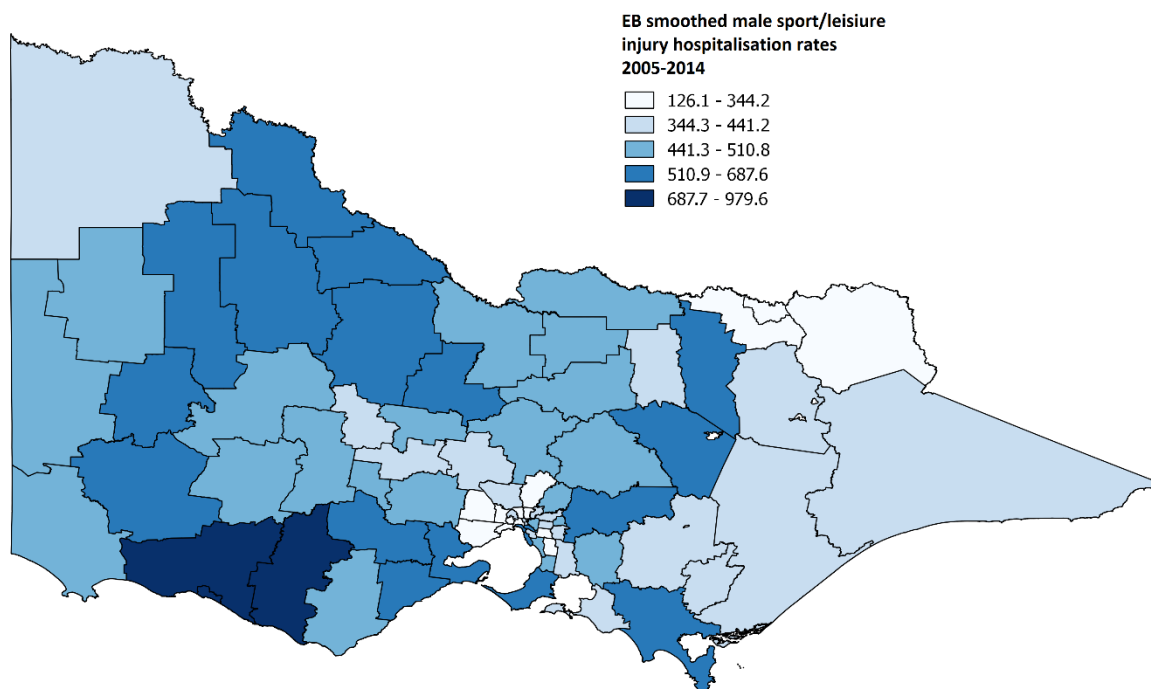


Figure 5.4: EB smoothed male sport/leisure injury hospitalisation rates per 100,000 male participants/year by Victorian LGAs, 2005–2014

A map depicting smoothed male sport/leisure injury hospitalisation rates is presented in Figure 5.4. Higher male sport/leisure injury hospitalisation rates were mostly observed in regional LGAs of western Victoria. Male sport/leisure injury hospitalisation rates across LGAs ranged from a low of 126.1/100,000 participants/year to a high of 979.6/100,000 male participants/year. The mean male sport/leisure injury hospitalisation rate across LGAs was 465.0/100,000 male participants/year and the standard deviation was 136.7/100,000 male participants/year.

5.2.2.2 *Female sport/leisure injury hospitalisations*

Figure 5.5 depicts the female sport/leisure injury hospitalisation rates per 100,000 female participants/year for each Victorian remoteness and socio-economic category. Across remoteness categories, the female sport/leisure injury hospitalisation rates ranged from a low of 145.4 per 100,000 female participants/year (95% CI: 143.1–147.7) in major cities to a high of 223.5 per 100,000 female participants/year (95% CI: 214.7–232.7) in outer regional areas. The estimated female sport/leisure injury hospitalisation rates of each remoteness area were

significantly different than the female sport/leisure injury hospitalisation rates of other remoteness categories.

Across socio-economic categories, the female sport/leisure injury hospitalisation rates ranged from a low of 132.2 per 100,000 female participants/year (95% CI: 128.1–136.4) in the most disadvantaged areas to a high of 174.7 per 100,000 female participants/year (95% CI: 170.3–179.1) in advantaged areas. The rate of female sport/leisure injury hospitalisations was significantly lower in most disadvantaged areas compared to female sport/leisure injury hospitalisation rates of other socio-economic categories of Victoria.

A map depicting smoothed female sport/leisure injury hospitalisation rates is presented in Figure 5.6. The higher rates were mostly observed in regional LGAs of western and eastern Victoria. The sport/leisure injury hospitalisation rates across LGAs ranged from a low of 126.1/100,000 female participants/year to a high of 979.6/100,000 female participants/year. A mean sport/leisure injury hospitalisation rate across LGAs was 465.0/100,000 female participants/year. The standard deviation was 136.7/100,000 female participants/year.

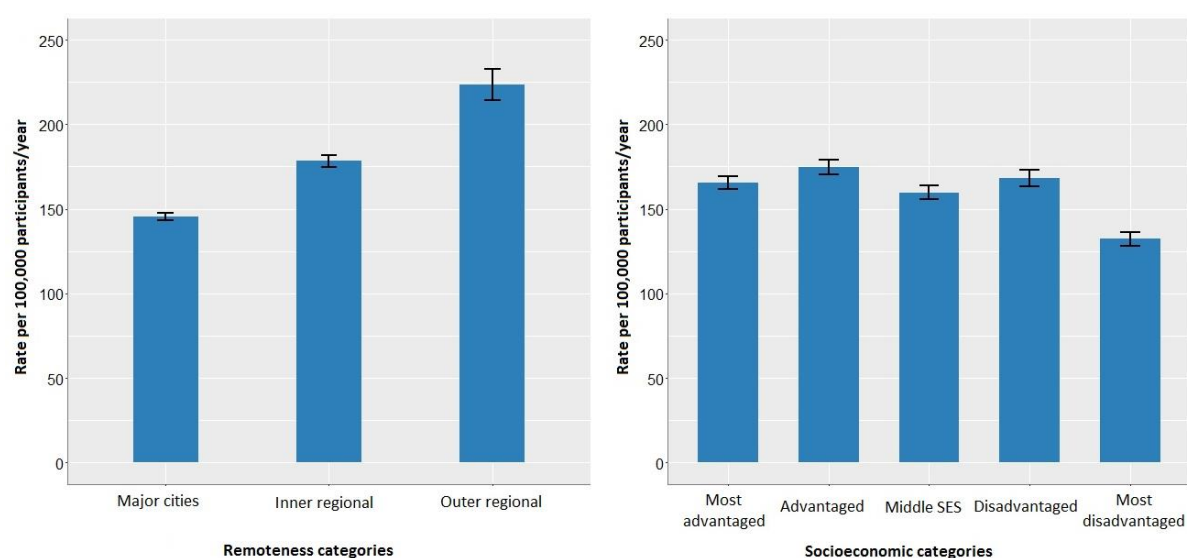


Figure 5.5: Sport/leisure female injury hospitalisation rates per 100,000 female participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

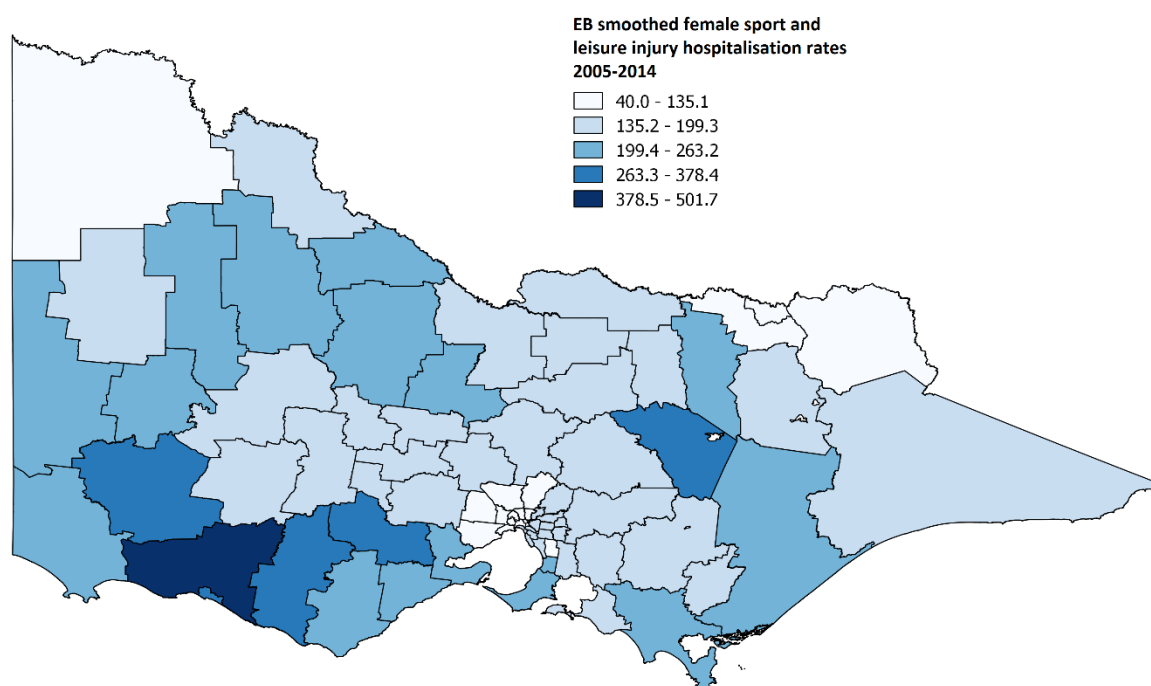


Figure 5.6: EB smoothed female sport/leisure injury hospitalisation rates per 100,000 female participants/year by LGAs of Victoria, 2005–2014

5.2.3 Age groups

5.2.3.1 *Sport/leisure injury hospitalisations in people aged 0-14 years*

Figure 5.7 shows age-specific sport/leisure injury hospitalisation rates for people aged 0–14 years per 100,000 participants/year for each Victorian remoteness and socio-economic category. Across remoteness categories, the age-adjusted sport/leisure injury hospitalisation rates for people aged 0–14 years ranged from a low of 404.7 per 100,000 participants/year (95% CI: 398.4–411.1) in major cities to a high of 549.7 per 100,000 participants/year (95% CI: 527.8–572.1) in outer regional areas. The estimated age-adjusted sport/leisure injury hospitalisation rates for people aged 0–14 years of each remoteness area was significantly different than the age-adjusted sport/leisure injury hospitalisation rates for those aged 0–14 years of other remoteness categories.

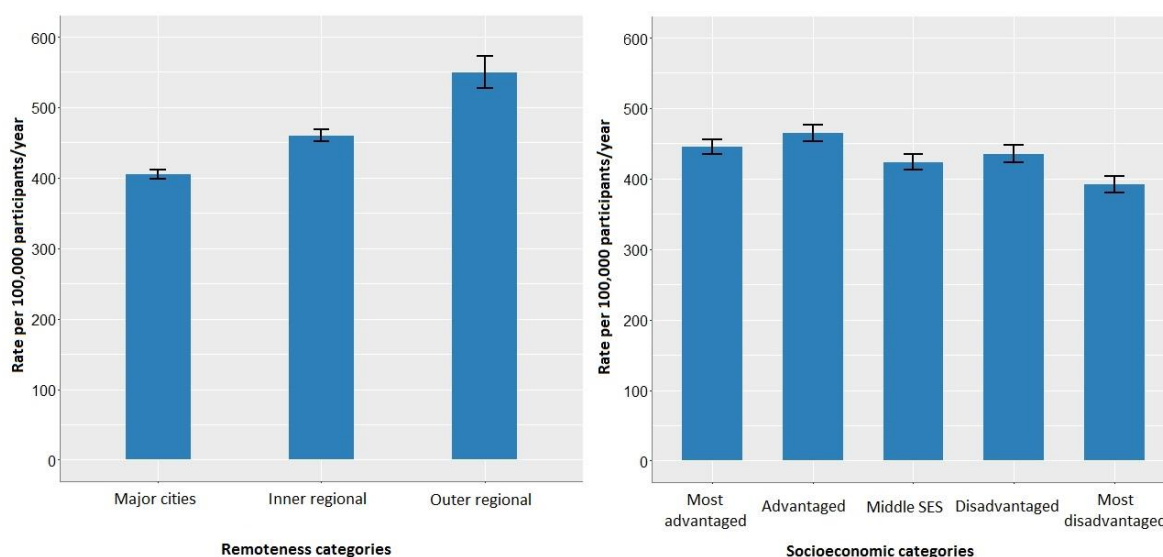


Figure 5.7: Age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 0–14 years by remoteness and socio-economic categories of Victoria, 2005–2014

Across socio-economic categories, the estimated age-adjusted sport/leisure injury hospitalisation rates for people aged 0–14 years ranged from a low of 391.8 per 100,000 participants/year (95% CI: 380.8–403.1) in the most disadvantaged areas to a high of 464.7 per 100,000 participants/year (95% CI: 453.7–476) in advantaged areas. The estimated age-adjusted sport/leisure injury hospitalisation rates for those aged 0–14 years was significantly lower in most disadvantaged areas compared to age-specific sport/leisure injury hospitalisation rates for those aged 0–14 years in other socio-economic categories of Victoria.

As shown in Figure 5.8, age-specific sport/leisure injury hospitalisation rates for people aged 0–14 years across Victorian LGAs ranged from a low of 75.1/100,000 participants/year to a high of 1159.1/100,000 participants/year. The higher rates were mostly observed in regional LGAs of Victoria. The mean rate across LGAs was 475.2/100,000 participants/year. The standard deviation was 175.7/100,000 participants/year.

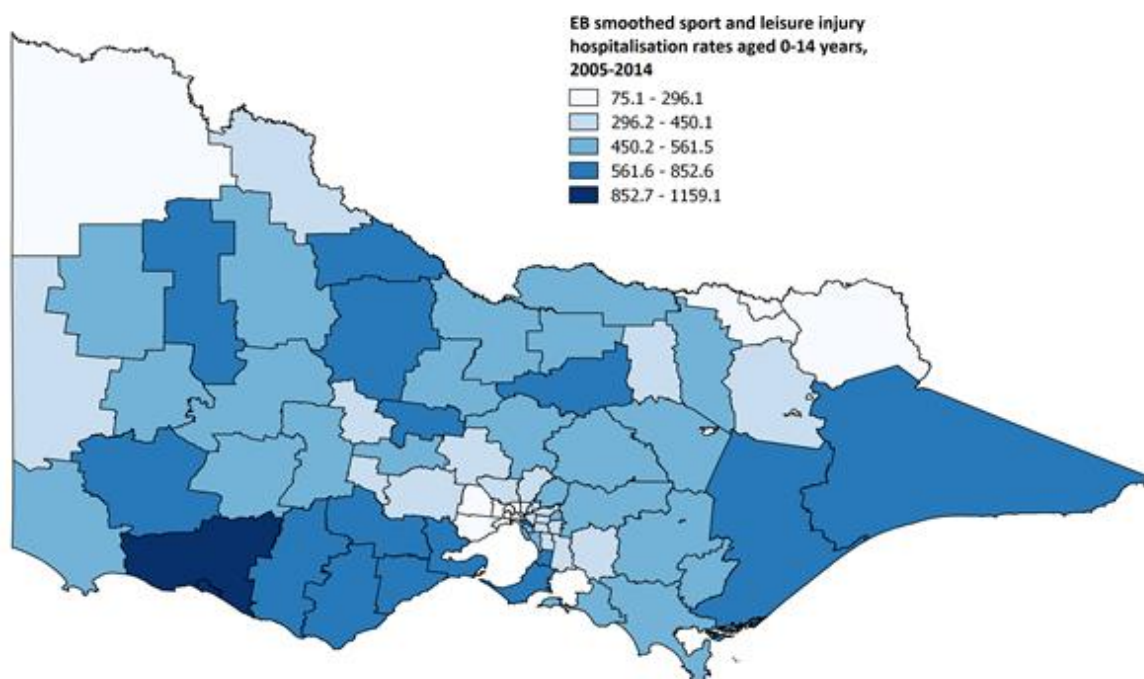


Figure 5.8: EB smoothed age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 0–14 years by Victorian LGAs, 2005–2014

5.2.3.2 *Sport/leisure injury hospitalisations in people aged 15–24 years*

Figure 5.9 shows the age-specific sport/leisure injury hospitalisation rates for people aged 15–24 years per 100,000 participants/year by Victorian remoteness and socio-economic categories. Across remoteness categories, the age-specific sport/leisure injury hospitalisation rates for those aged 15–24 years ranged from a low of 438.8 per 100,000 participants/year (95% CI: 431.9–445.8) in major cities to a high of 895.8 per 100,000 participants/year (95% CI: 861.9–930.8) in outer regional areas. The estimated age-adjusted sport/leisure injury hospitalisation rates for people aged 15–24 years of each remoteness area was significantly different than the age-specific sport/leisure injury hospitalisation rates for those aged 15–24 years in other remoteness categories. Interestingly, in this age group, there was a significant difference in sport/leisure injury hospitalisation rates across remoteness categories. This was not evident in the other age groups.

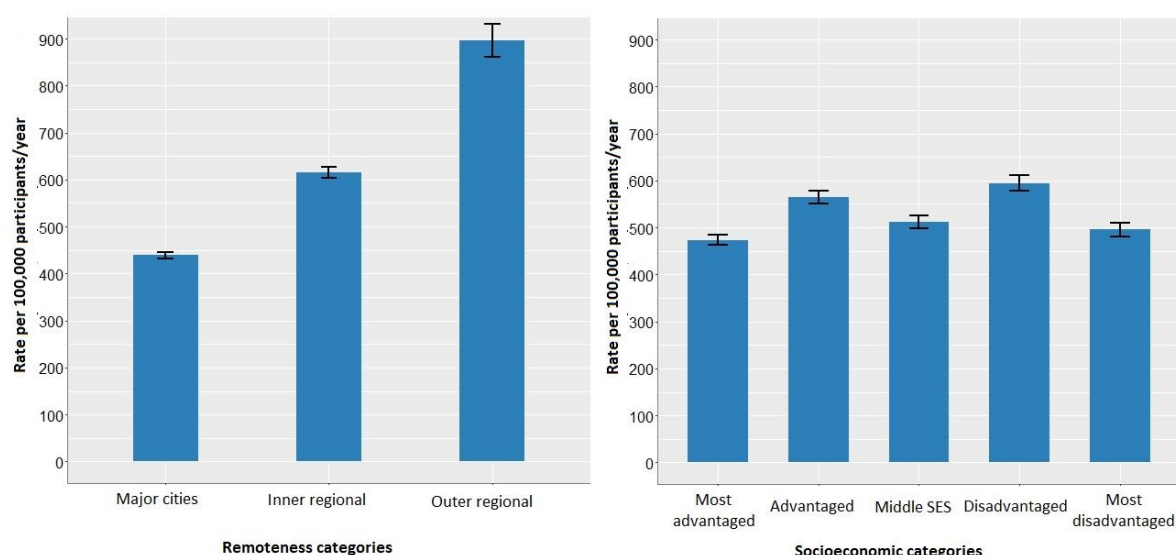


Figure 5.9: Age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 15–24 years by remoteness and socio-economic categories of Victoria, 2005–2014

Across socio-economic categories, the estimated age-specific sport/leisure injury hospitalisation rates for people aged 15–24 years ranged from a low of 473.3 per 100,000 participants/year (95% CI: 380.8–403.1) in the most advantaged areas to a high of 594.5 per 100,000 participants/year (95% CI: 577.9–611.4) in disadvantaged areas. The estimated age-adjusted sport/leisure injury hospitalisation rates for people aged 15–24 years were significantly higher in disadvantaged and advantaged areas compared to age-adjusted sport/leisure injury hospitalisation rates for those aged 15–24 years in other socio-economic categories in Victoria.

As depicted in Figure 5.10, estimated age-specific sport/leisure injury hospitalisation rates for people aged 15–24 years across Victorian LGAs ranged from a low of 157.8/100,000 participants/year to a high of 1456.5/100,000 participants/year. The higher rates were mostly observed in regional LGAs in western Victoria. The mean rate across LGAs was 702.0/100,000 participants/year. The standard deviation was 301.9/100,000 participants/year.

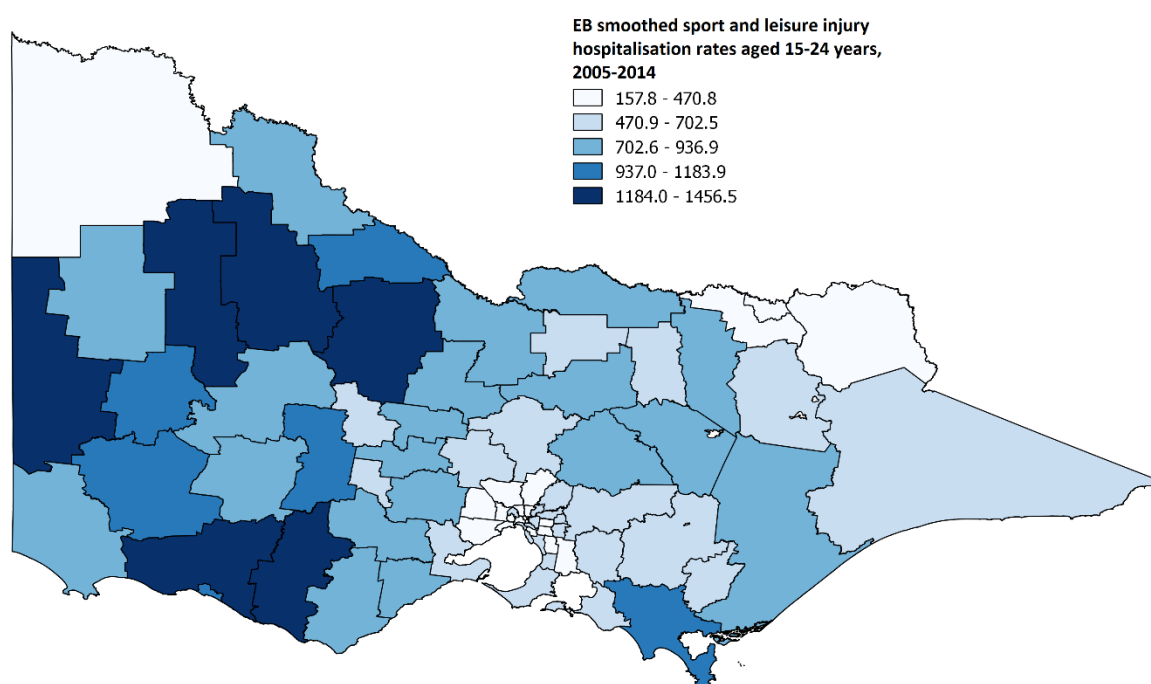


Figure 5.10: EB smoothed age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 15–24 years by Victorian LGAs, 2005–2014

5.2.3.3 *Sport/leisure injury hospitalisations in people aged 25–44 years*

Figure 5.11 illustrates age-adjusted sport/leisure injury hospitalisation rates for people aged 25–44 years per 100,000 participants/year for each Victorian remoteness and socio-economic category. Across remoteness categories, the age-adjusted sport/leisure injury hospitalisation rates for people aged 25–44 years ranged from a low of 261.7 per 100,000 participants/year (95% CI: 257.9–265.6) in major cities to a high of 385.3 per 100,000 participants/year (95% CI: 368.1–403.1) in outer regional areas. The estimated age-specific sport/leisure injury hospitalisation rates for people aged 25–44 years of each remoteness area was significantly different than the age-specific sport/leisure injury hospitalisation rates for people aged 25–44 years of other remoteness categories.

Across socio-economic categories, the age-specific sport/leisure injury hospitalisation rates for people aged 25–44 years ranged from a low of 220.7 per 100,000 participants/year (95% CI: 380.8–403.1) in the most disadvantaged areas to a high of 306.5 per 100,000 participants/year (95% CI: 300.4–312.6) in the most advantaged areas. The estimated age-specific sport/leisure injury hospitalisation rates for people aged 25–44 years was

significantly lower in most disadvantaged areas compared to age-specific sport/leisure injury hospitalisation rates for those aged 25–44 years in other socio-economic categories of Victoria. The estimated age-specific sport/leisure injury hospitalisation rates for those aged 25–44 years was significantly higher in most advantaged and advantaged areas compared to the age-specific sport/leisure injury hospitalisation rates for those aged 25–44 years in other socio-economic categories of Victoria.

As shown in Figure 5.12, age-specific sport/leisure injury hospitalisation rates for people aged 25–44 years across Victorian LGAs ranged from a low of 93.7/100,000 participants/year to a high of 628.5/100,000 participants/year. The higher age-specific sport/leisure injury hospitalisation rates for those aged 25–44 years was mostly observed in regional LGAs in western Victoria. The mean rate across LGAs was 318.4/100,000 participants/year. The standard deviation was 95.8/100,000 participants/year.

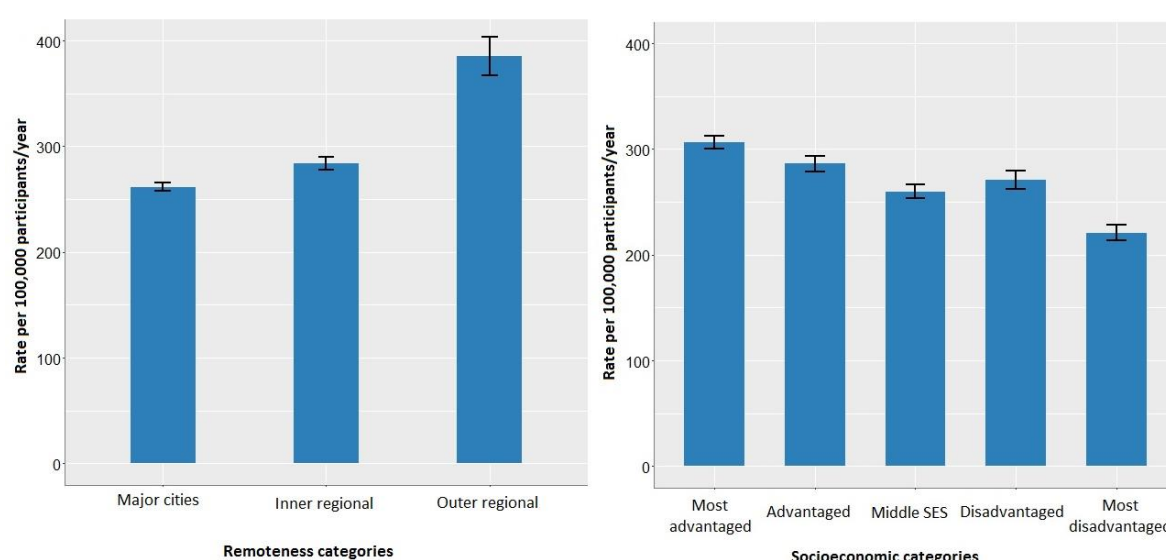


Figure 5.11: Age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 25–44 years by remoteness and socio-economic categories of Victoria, 2005–2014

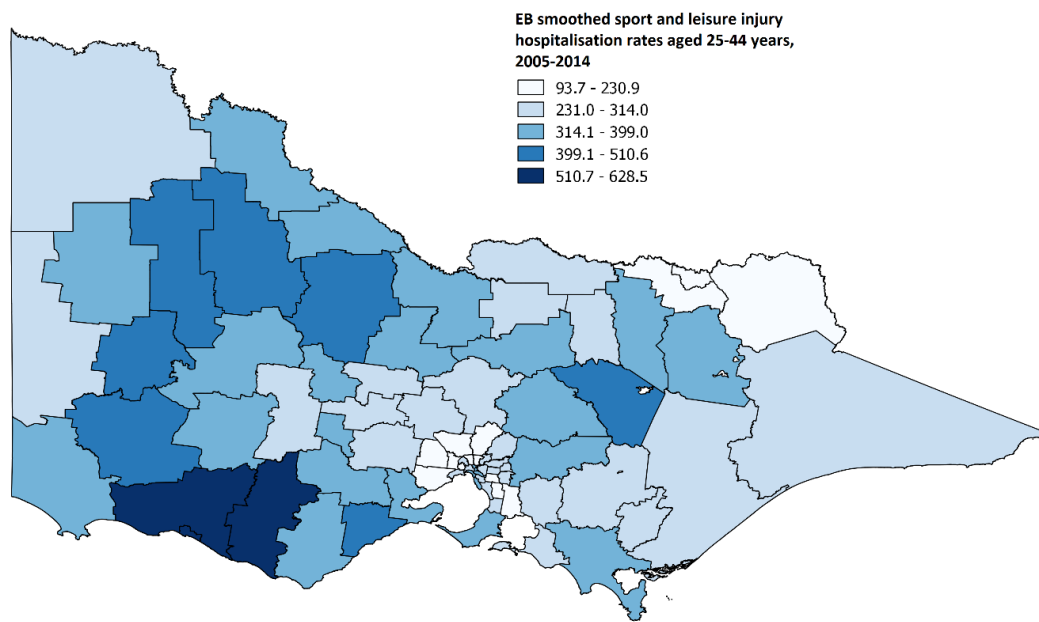


Figure 5.12: EB smoothed age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 25–44 years by Victorian LGAs, 2005–2014

5.2.3.4 *Sport/leisure injury hospitalisations in people aged 45–64 years*

Figure 5.13 depicts age-specific sport/leisure injury hospitalisation rates for people aged 45–64 years per 100,000 participants/year for each remoteness and socioeconomic category in Victoria. Across remoteness categories, the age-specific sport/leisure injury hospitalisation rates for those aged 45–64 years ranged from a low of 116.1 per 100,000 participants/year (95% CI: 107.8–124.9) in major cities to a high of 124.5 per 100,000 participants/year (95% CI: 120.6–128.8) in inner regional areas. The estimated age-specific sport/leisure injury hospitalisation rates for people aged 45–64 years of each remoteness area was not significantly different than the age-specific sport/leisure injury hospitalisation rates for those aged 45–64 years of other remoteness categories.

Across socio-economic categories, the age-specific sport/leisure injury hospitalisation rates for people aged 45–64 years rate ranged from a low of 84.8 per 100,000 participants/year (95% CI: 80.2–89.6) in the most advantaged areas to a high of 156.5 per 100,000 participants/year (95% CI: 151.6–161.5) in disadvantaged areas. The estimated age-specific sport/leisure injury hospitalisation rates for people aged 45–64 years were significantly lower in most disadvantaged areas and higher in most advantaged areas compared to age-specific

sport/leisure injury hospitalisation rates for those aged 45–64 years in other socio-economic categories of Victoria. In this age group, the sport/leisure injury hospitalisation rates observed decreased in line with declines in SES.

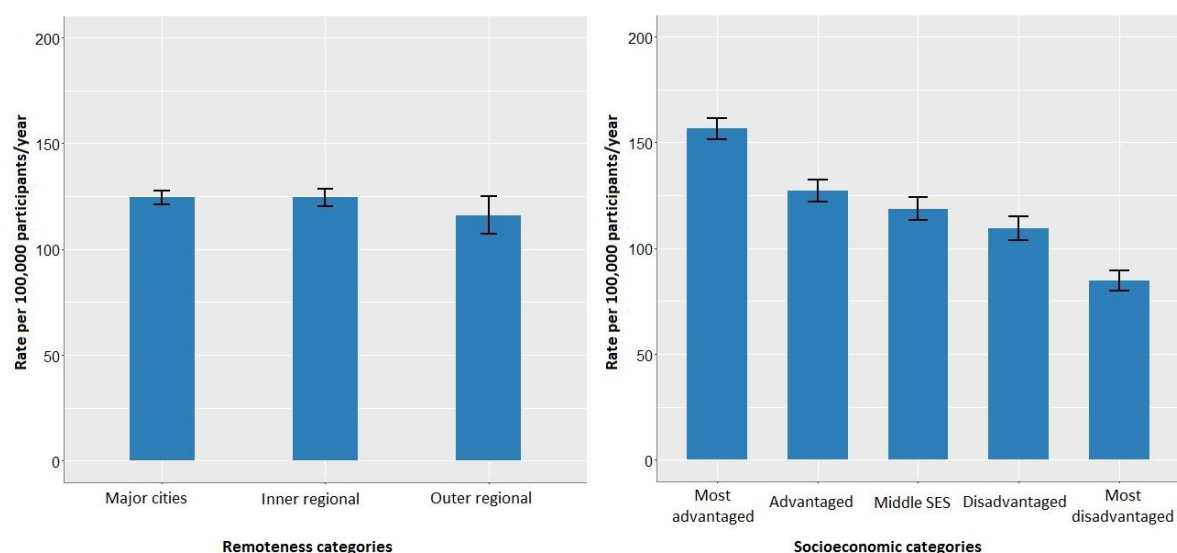


Figure 5.13: Age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 45–64 years by remoteness and socio-economic categories of Victoria, 2005–2014

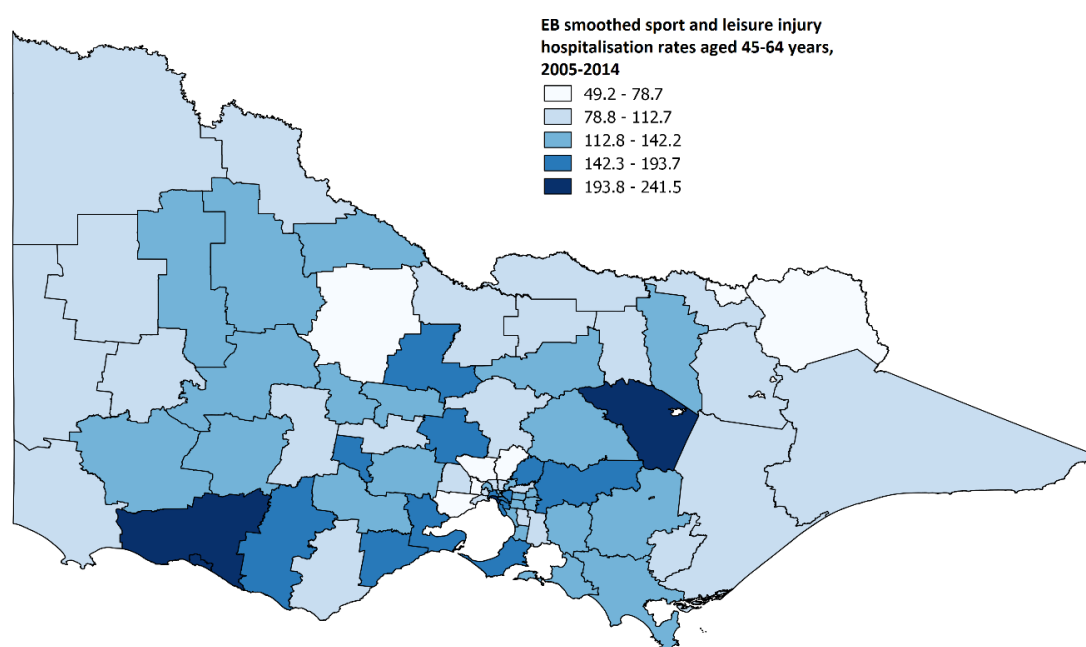


Figure 5.14: EB smoothed age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged 45–64 years by LGAs of Victoria, 2005–2014

As shown in Figure 5.14, age-specific sport/leisure injury hospitalisation rates for people aged 45–64 years across Victorian LGAs ranged from a low of 49.2/100,000 participants/year to a high of 241.5/100,000 participants/year. The higher rates were mostly observed in regional LGAs of inner regional areas and major cities of Victoria. The mean rate across LGAs was 125.6/100,000 participants/year. The standard deviation was 40.8/100,000 participants/year.

5.2.3.5 Sport/leisure injury hospitalisations in people aged over 65 years

Figure 5.15 shows age-specific sport/leisure injury hospitalisation rates for people aged over 65 years per 100,000 participants/year for each remoteness and socio-economic category of Victoria. Across remoteness categories, the age-specific sport/leisure injury hospitalisation rates for those aged over 65 years ranged from a low of 132.0 per 100,000 participants/year (95% CI: 119.9–145.1) in major cities to a high of 149.7 per 100,000 participants/year (95% CI: 144.8–154.8) in outer regional areas. The estimated age-specific sport/leisure injury hospitalisation rates for people aged 45–64 years of each remoteness area was not significantly different than the age-specific sport/leisure injury hospitalisation rates for those aged over 65 years in other remoteness categories.

Across socio-economic categories, the age-specific sport/leisure injury hospitalisation rates for people aged over 65 years ranged from a low of 99.2 per 100,000 participants/year (95% CI: 91.8–107.1) in the most disadvantaged areas to a high of 170.8 per 100,000 participants/year (95% CI: 161.5–180.5.5) in advantaged areas. The age-specific sport/leisure injury hospitalisation rates for those aged over 65 years is significantly lower in most disadvantaged areas compared to age-specific sport/leisure injury hospitalisation rates for those aged over 65 years in other socio-economic categories of Victoria. The estimated age-specific sport/leisure injury hospitalisation rates for people aged over 65 years were significantly higher in most advantaged and advantaged areas compared to age-specific sport/leisure injury hospitalisation rates for those aged over 65 years of other socio-economic categories of Victoria

As shown in Figure 5.16, age-specific sport/leisure injury hospitalisation rates for people aged over 65 years across Victorian LGAs ranged from a low of 45.8/100,000 participants/year to a high of 578.8/100,000 participants/year. The higher rates were mostly observed in LGAs of inner regional areas and major cities of Victoria. The mean rate across

LGAs was 142.6/100,000 participants/year. The standard deviation was 67.4/100,000 participants/year.

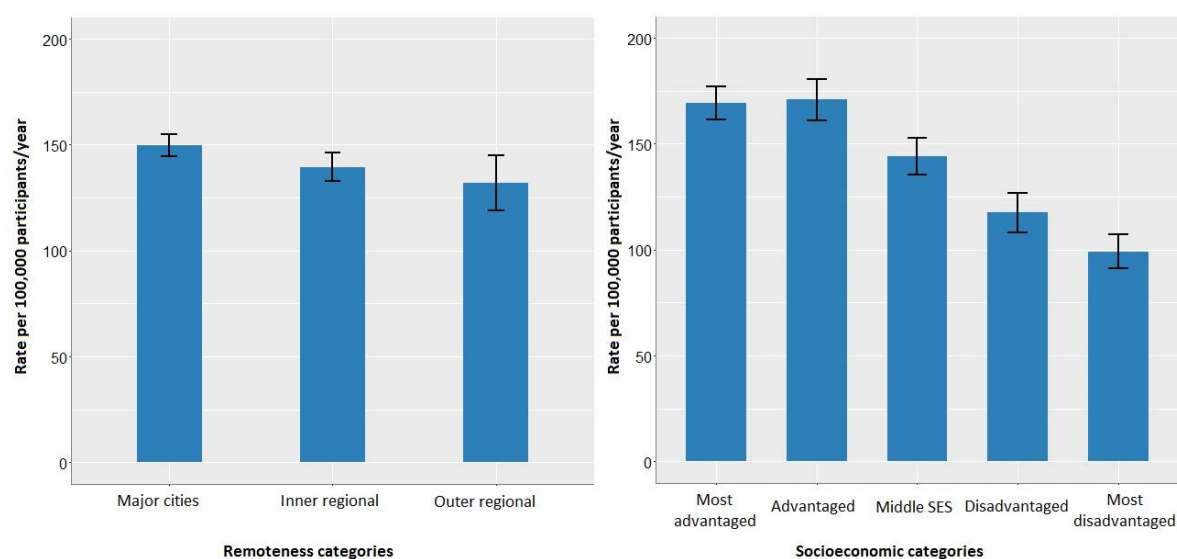


Figure 5.15: Age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged over 65 years by remoteness and socio-economic categories of Victoria, 2005–2014

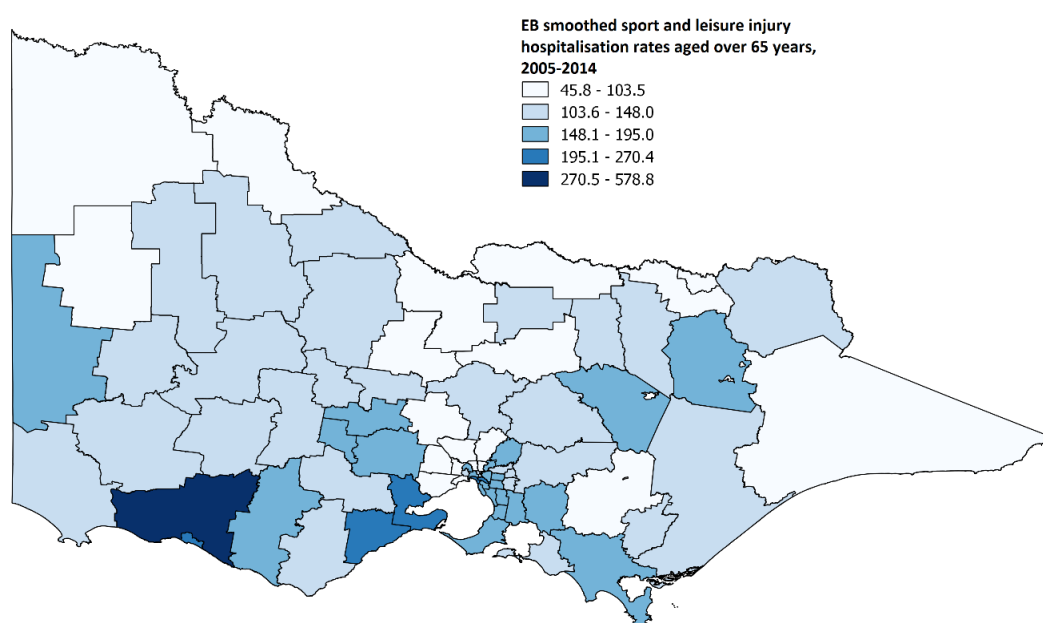


Figure 5.16: EB smoothed age-specific sport/leisure injury hospitalisation rates per 100,000 participants/year in people aged over 65 years by Victorian LGAs, 2005–2014

5.2.4 Specific sports

5.2.4.1 Australian Football injury hospitalisations

Figure 5.17 depicts the Australian Football injury hospitalisation rates per 100,000 participants/year for each remoteness and socio-economic category of Victoria. Across remoteness categories, the Australian Football injury hospitalisation rates ranged from a low of 997.3 per 100,000 participants/year (95% CI: 973.2–1022.0) in major cities to a high of 2,938.9 per 100,000 participants/year (95% CI: 2,810.1–3,072.2) in outer regional areas. The estimated Australian Football injury hospitalisation rates of each remoteness area were significantly different than the Australian Football injury hospitalisation rates of other remoteness categories.

Across socio-economic categories, the Australian Football injury hospitalisation rate ranged from a low of 1,079.1 per 100,000 participants/year (95% CI: 1,042.6–1,116.6) in most advantaged areas to a high of 1,883.1 per 100,000 participants/year (95% CI: 1,816.2–1,951.8) in disadvantaged areas. The rates of Australian Football injury hospitalisations was significantly lower in the most advantaged areas and significantly higher in disadvantaged areas compared to Australian Football injury hospitalisation rates in other socio-economic categories of Victoria.

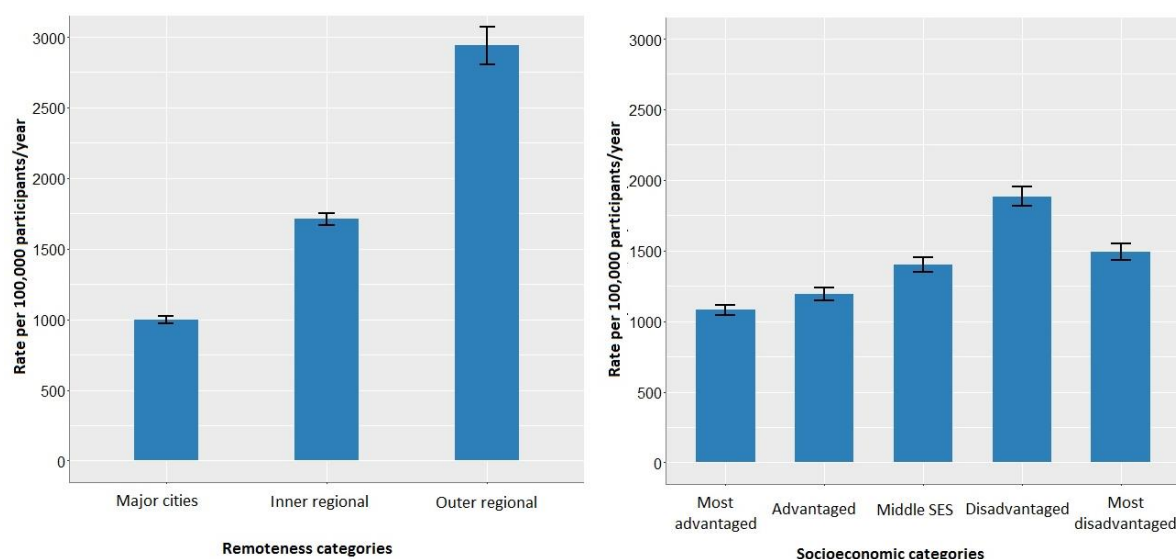


Figure 5.17: Australian Football injury hospitalisation rates per 100,000 participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

As shown in Figure 5.18, Australian Football injury hospitalisation rates across Victorian LGAs ranged from a low of 303.4/100,000 participants/year to a high of 5,549.1/100,000 participants/year. Higher Australian Football injury hospitalisation rates were mostly observed in regional LGAs in western Victoria. The mean Australian Football injury hospitalisation rate across LGAs was 1,958.5/100,000 participants/year. The standard deviation was 1,178.1/100,000 participants/year.

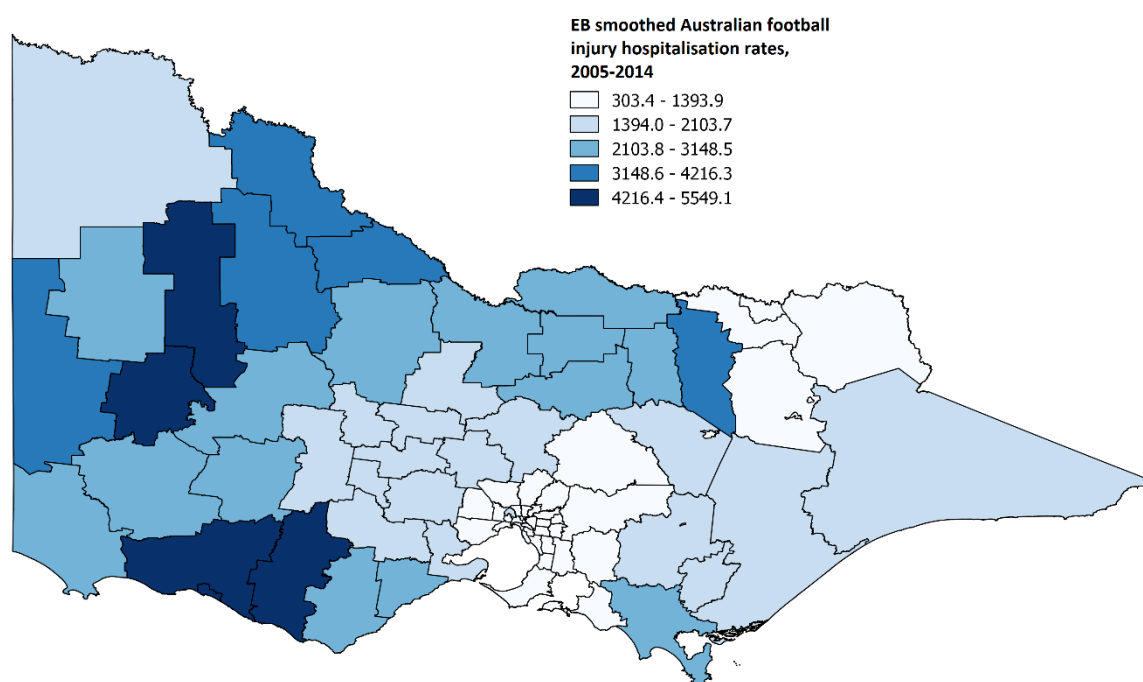


Figure 5.18: EB smoothed Australian Football injury hospitalisation rates by Victorian LGAs, 2005–2014

5.2.4.2 Soccer injury hospitalisations

Figure 5.19 shows the soccer injury hospitalisation rates per 100,000 participants/year for the remoteness and socio-economic categories of Victoria. Across remoteness categories, the soccer injury hospitalisation rates ranged from a low of 208.9 per 100,000 participants/year (95% CI: 174.8–247.7) in outer regional areas to a high of 726.2 per 100,000 participants/year (95% CI: 705.0–747.8) in major cities. The estimated soccer injury hospitalisation rates of each remoteness area were significantly different than the soccer injury hospitalisation rates of other remoteness categories.

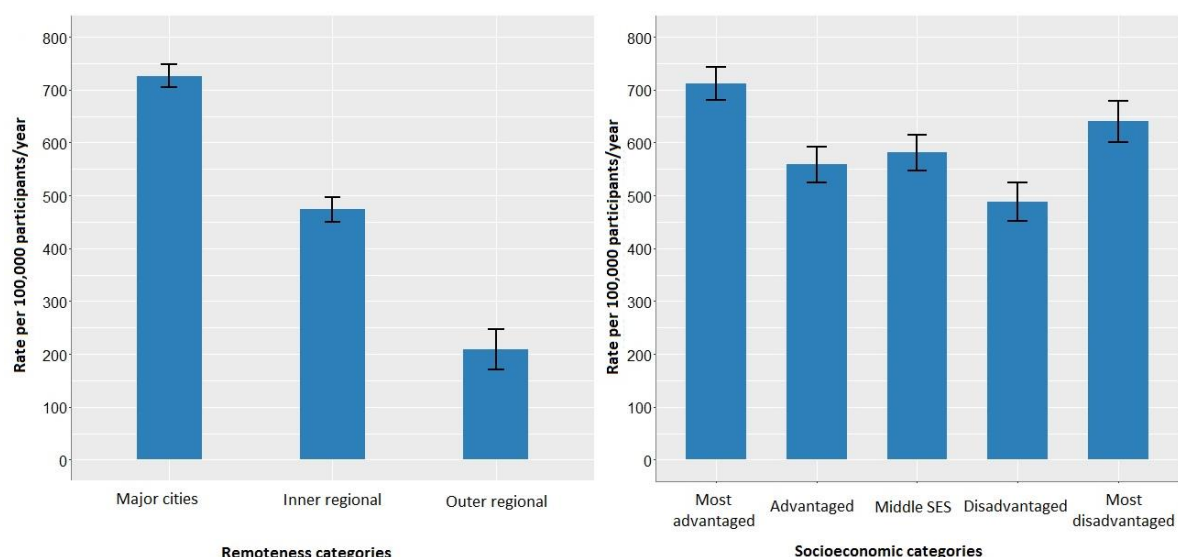


Figure 5.19: Soccer injury hospitalisation rates per 100,000 participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

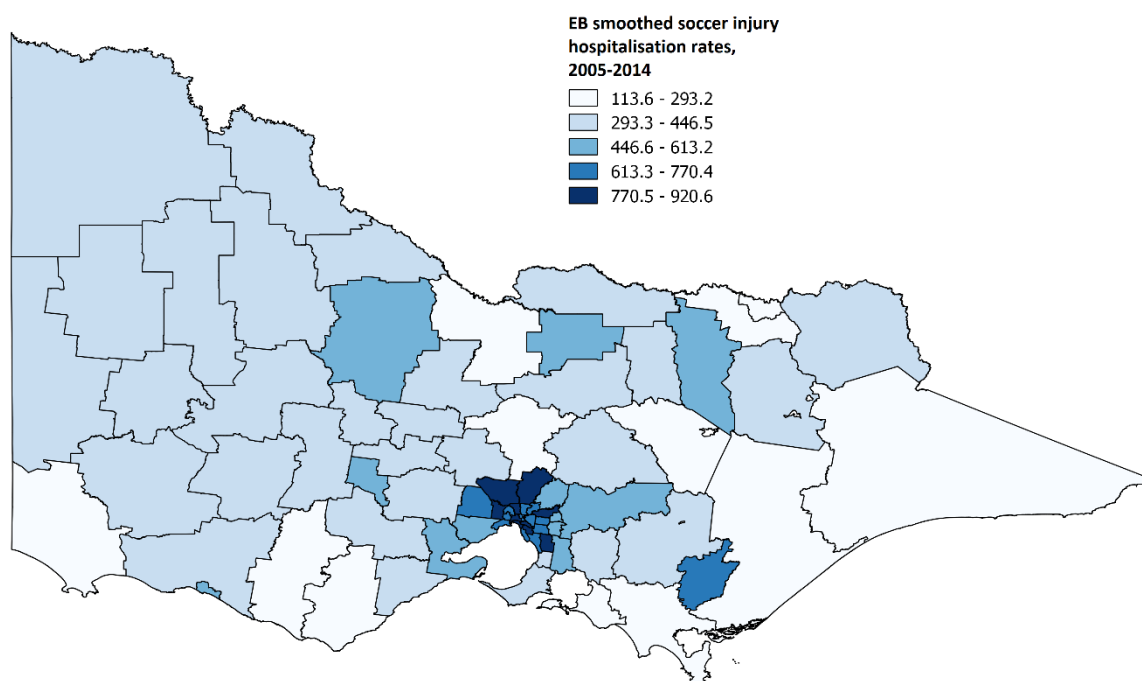


Figure 5.20: EB smoothed soccer injury hospitalisation rates by Victorian LGAs, 2005–2014

Across socio-economic categories, the soccer injury hospitalisation rates ranged from a low of 487.3 per 100,000 participants/year (95% CI:452.7–523.8) in disadvantaged areas to a high

of 711.8 per 100,000 participants/year (95% CI:681.4–743.2) in the most advantaged areas. The rates of soccer injury hospitalisations were significantly lower in disadvantaged areas and significantly higher in most advantaged areas compared to soccer injury hospitalisation rates of other socio-economic categories of Victoria.

As illustrated in Figure 5.20, soccer injury hospitalisation rates across Victorian LGAs ranged from a low of 113.6/100,000 participants/year to a high of 920.6/100,000 participants/year. Higher soccer injury hospitalisation rates were mostly observed in LGAs of major Victorian cities. The mean soccer injury hospitalisation rate across LGAs was 496.0/100,000 participants/year. The standard deviation was 204.5/100,000 participants/year.

5.3.4.3 Basketball injury hospitalisations

Figure 5.21 shows the basketball injury hospitalisation rates per 100,000 participants/year for each remoteness and socio-economic category of Victoria. Across remoteness categories, the BIH rates ranged from a low of 229.3 per 100,000 participants/year (95% CI: 201.4–259.9) in outer regional areas to a high of 335.5 per 100,000 participants/year (95% CI: 324.4–346.8) in major cities. The estimated BIH rates of each remoteness area were significantly different than the BIH rates of other remoteness categories.

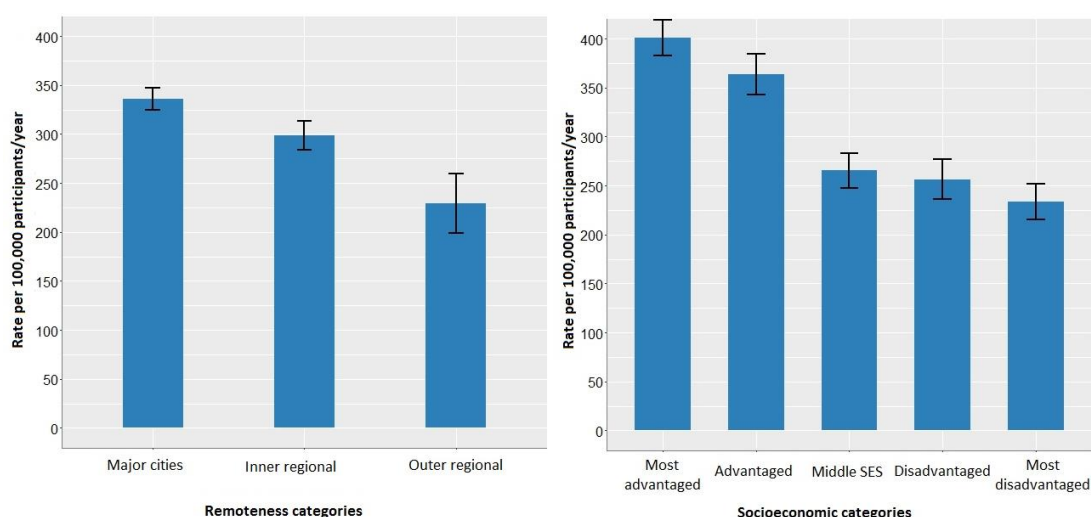


Figure 5.21: Basketball injury hospitalisation rates per 100,000 participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

Across socio-economic categories, the BIH rate ranged from a low of 233.4 per 100,000 participants/year (95% CI:216.6–251.2) in the most disadvantaged areas to a high of 400.5

per 100,000 participants/year (95% CI:383.0–418.7) in the most advantaged areas. The rates of BIHs were significantly higher in most advantaged and advantaged areas compared to BIH rates of other socio-economic categories of Victoria.

As shown in Figure 5.22, BIH rates across Victorian LGAs ranged from a low of 97.1/100,000 participants/year to a high of 616.8/100,000 participants/year. The higher BIH rates were mostly observed in LGAs in eastern Victoria. The mean BIH rate across LGAs was 285.7/100,000 participants/year. The standard deviation was 107.6/100,000 participants/year.

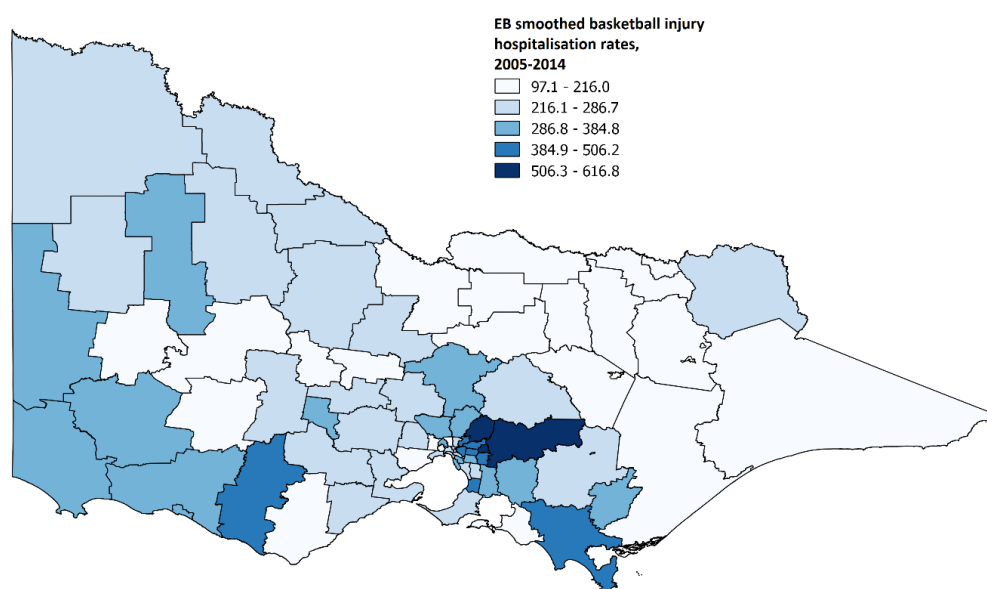


Figure 5.22: EB smoothed basketball injury hospitalisation rates by Victorian LGAs, 2005–2014

5.2.4.4 *Cricket injury hospitalisations*

Figure 5.23 depicts the cricket injury hospitalisation rates per 100,000 participants/year across remoteness and socio-economic categories. Across remoteness categories, the cricket injury hospitalisation rates ranged from a low of 232.7 per 100,000 participants/year (95% CI: 221.1–244.7) in outer regional areas to a high of 297.7 per 100,000 participants/year (95% CI: 257.6–342.1) in major cities. The estimated cricket injury hospitalisation rates of

major cities was significantly different than the cricket injury hospitalisation rates of the outer regional areas.

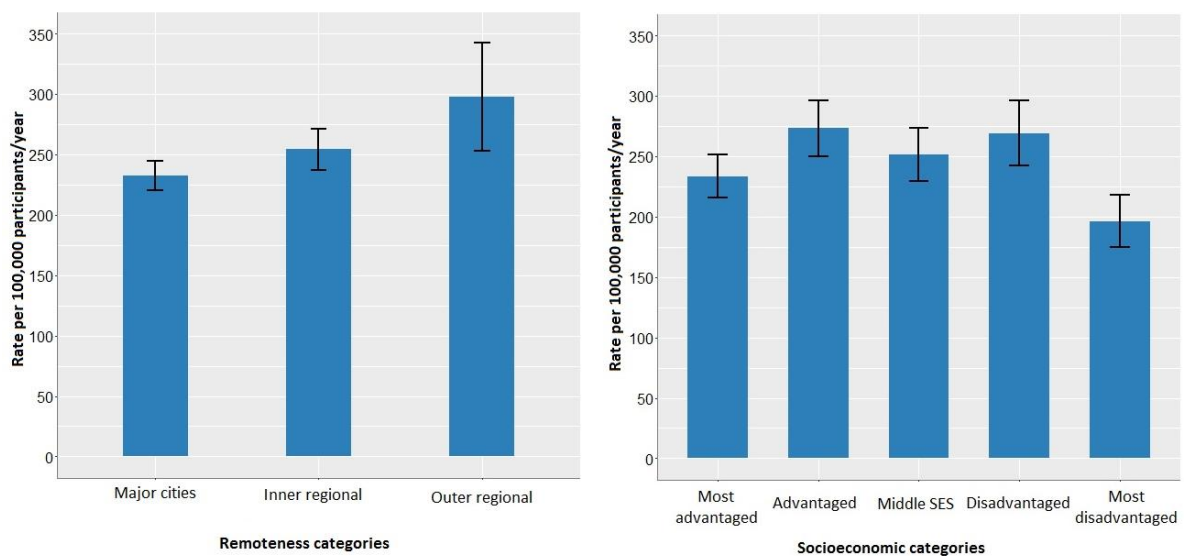


Figure 5.23: Cricket injury hospitalisation rates per 100,000 participants/year by remoteness and socio-economic categories of Victoria, 2005–2014

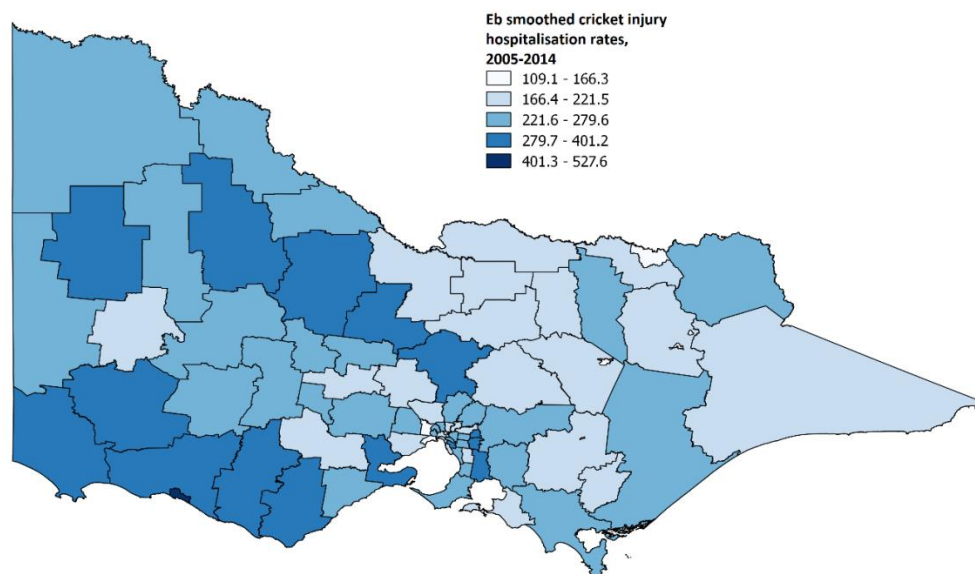


Figure 5.24: EB smoothed cricket injury hospitalisation rates by Victorian LGAs, 2005–2014

Across socio-economic categories, the cricket injury hospitalisation rates ranged from a low of 196.3 per 100,000 participants/year (95% CI:176.3–217.9) in the most disadvantaged areas to a high of 273.1 per 100,000 participants/year (95% CI:251.2–296.4) in advantaged areas.

The rates of cricket injury hospitalisations were significantly lower in the most disadvantaged areas compared to the BIH rates of other socio-economic categories of Victoria.

Figure 5.24 indicates that cricket injury hospitalisation rates across Victorian LGAs ranged from a low of 109.1/100,000 participants/year to a high of 527.6/100,000 participants/year. The higher cricket injury hospitalisation rates were observed mostly in LGAs in southern Victoria. The mean cricket injury hospitalisation rate across LGA was 246.0/100,000 participants/year; the standard deviation was 59.5/100,000 participants/year.

5.3 Conclusions

In this chapter, sport/leisure injury hospitalisation incidence rates were examined by remoteness and socio-economic regions of Victoria. The geographic patterns of sport/leisure injury hospitalisations were explored by mapping estimated incidence rates of Victorian LGAs.

The examination of overall sport/leisure injury hospitalisations revealed that sport/leisure injury hospitalisation rates were higher along with increasing rurality. In contrast, there was no clear relationship between overall sport/leisure injury hospitalisation rates and socio-economic regions. These findings are consistent with those reported in NSW (Finch & Boufous, 2009; Lam, 2005). One possible explanation for this consistency could be the limited availability of safe sport/leisure facilities with trained professionals in regional areas compared to metropolitan areas (Finch & Boufous, 2009; Orchard, 2002; Swan et al., 2009). In addition, due to the limited availability of healthcare facilities other than hospitals in regional areas, people are perhaps more likely to be hospitalised as a result of the injury in these areas.

Higher sport/leisure injury hospitalisation rates were observed in regions where many people have higher incomes and are most likely to be involved in skilled occupations. It is important to understand the reason for this trend because a low number of hospitalisations might be expected in such areas because of the availability of safe sport/leisure facilities. Further, sport/leisure participants have the financial resources to use those facilities. However, the observed pattern could also reflect a differential pattern of participation in sport/leisure activities (Finch & Boufous, 2009). Considering participation in all sport/leisure activities, higher participation rates are reported in higher socio-economic regions (Eime, Charity,

Harvey & Payne, 2015) because people in these regions have more financial resources than people from disadvantaged regions. Thus, they can afford the costs of participation in sport/leisure activities (e.g., membership fees and sports gears).

Sport/leisure injury hospitalisation rates by demographic characteristics and activities demonstrated a differential pattern across socio-economic and remoteness regions in some demographic and activity categories analysed in this chapter. For example, in contrast to other age groups, sport/leisure injury hospitalisation rates in people aged 45 years and over were higher in major cities than they were in inner and outer regional areas, and most commonly in high socioeconomic areas. Further, the pattern of sport/leisure injury hospitalisation rates by selected specific sports was significantly different across socio-economic and remoteness categories. For example, the basketball and soccer injury hospitalisation rates were higher in major cities, while Australian Football and cricket injury hospitalisation rates were greater in regional areas.

Maps depicting sport/leisure injury hospitalisation rates by LGA were presented to describe the geographical distribution of estimated rates. In most cases, higher overall rates were observed in the LGAs of western Victoria. The investigation of rates by LGA demonstrated the variation in sport/leisure injury hospitalisation rates within regional Victorian LGAs. Only a few LGAs of regional Victoria (south-west region) have very high incidence rates compared to other Victorian LGAs. Importantly, the observed spatial pattern by age groups and selected sports differed from one another. For example, there was a higher incidence of Australian Football hospitalisations in western regional Victorian LGAs, but the incidence of soccer injury hospitalisations was higher in metropolitan Victorian LGAs. Therefore, the spatial pattern at the small geographical scale must be considered to better identify the target population or region for preventive efforts.

The maps generated in this chapter were discussed based on visual inspection. However, visual inspection is not sufficient to test the null hypothesis that injury rates by LGA are randomly distributed. Therefore, the next chapter of this thesis will focus on applying spatial cluster methods to describe the geospatial pattern of sport/leisure injuries statistically.

Chapter 6: Use of Geographic Analysis to Identify Areas Presenting High and Low Risk of Sport/Leisure Injury Hospitalisations

6.1 Introduction

Findings of Chapter 5 indicated a geographical variation of sport and leisure injuries in Victoria. However, the findings mostly relied on a visual inspection of created maps, which does not quantify the nature of the geographical variation. To quantify the geographical variation observed in Chapter 5, this chapter will focus on applying clustering or cluster detection methods. The application of clustering or cluster detection methods to identify geospatial clusters within the geographic distribution of data is described in Chapter 3. The investigation of geospatial clusters is considered a form of descriptive epidemiological study to generate ideas and hypotheses prior to confirmatory epidemiological studies (Wartenberg & Greenberg, 1993). Geospatial clusters of high values in area-level data provide an indication of which regions have a higher and lower risk of disease or injury compared with other areas (Lawson, 2001).

There has been increased interest in recent years in the application of clustering and cluster detection methods in injury research (Auchincloss et al., 2012; Singh et al., 2016). These methods have been applied to injury-cause categories such as burns, falls and road traffic crashes (Chan, Law & Seliske, 2012; Erdogan, 2009; Lawrence, Stevenson, Oxley & Logan, 2015; Poulos, Hayen, Chong & Finch, 2009; Singh et al., 2016). For example, a NSW study demonstrated a higher risk of severe burns in Western Sydney (Goltsman et al., 2014). Similarly, a study conducted in Ontario, Canada identified dissemination areas (smallest geographical unit in which census data are released) with higher relative risk of falls in older people (Chan et al., 2012). Finally, a study conducted in NSW identified the high-risk LGAs for pedestrian and pedal cycle injuries (Poulos, Chong, Olivier & Jalaludin, 2012). Information about high-risk populations or geographical areas are strong evidence bases for prioritising public health interventions and further investigating risk factors.

Despite the many practical advantages of using clustering and cluster detection methods in injury research, so far, no sport/leisure injury research has applied these methods. Therefore, this chapter aims to use clustering and cluster detection methods to identify geospatial clusters of high and low sport/leisure injury hospitalisations rates for all sport/leisure

activities and, specifically, for four popular sports. Further, it aims to understand the differences in the distribution of sport/leisure injury hospitalisations by demographic and injury-outcome variables of the identified geospatial clusters of high and low injury hospitalisation rates in Victoria.

6.2 Methods

The sport and leisure injury hospitalisation dataset used in this chapter is described in Chapter 4. The EB smoothed overall and sport-specific (four sports having a high number of hospitalisations) sport/leisure injury hospitalisation rates were calculated (see Table 4.11).

To investigate the geographical pattern of sport/leisure injuries, a wide range of clustering and cluster detection methods are available (Auchincloss et al., 2012; Fritz, Schuurman, Robertson & Lear, 2013; Singh et al., 2016). For the aggregated data by region, global methods such as *Moran's I* (Moran, 1950) and Geary's *C* (Geary, 1954) can be applied to test for spatial autocorrelation. For the LGA sport/leisure injury hospitalisation data, the spatial autocorrelation is tested using the Moran's *I* method because this method takes into account both LGA location and LGAs' sport/leisure injury hospitalisation rates simultaneously to measure spatial autocorrelation; and is most commonly used in injury research (Moran, 1950; Singh et al., 2016).

To identify the hot spots or local clusters, local methods such as local Moran's *I*, local Geary's *C*, and Getis-Ord *Gi** can be applied (Singh et al., 2016). For the sport/leisure injury hospitalisation data presented here, the Getis-Ord *Gi** (Getis & Ord, 1992) method is used to identify hot and cold spots. The *Gi** is the preferred hot spot analysis method for several reasons (Braithwaite & Li, 2007). First, the statistics identify areas with significantly higher local averages than global averages, which is the typical definition of a hot spot. Second, *Gi** does not require that an LGA and its neighbouring LGA have injury rates distinguishable from (either higher or lower than) the statewide average, as would be required in the local Moran's *I* method. Third, *Gi** can identify LGAs with high injury rates, even if the LGA's injury rate is not different from the statewide average.

The Moran's *I* and Getis-Ord *Gi** methods were used for all selected outcome variables:

- sport/leisure injury hospitalisation rates
- Australian Football injury hospitalisation rates

- soccer injury hospitalisation rates
- basketball injury hospitalisation rates
- cricket injury hospitalisation rates

To use these methods, the spatial relationship among the LGAs first has to be conceptualised. The spatial relationship defines the neighbour relationship of each LGA within the context of neighbouring LGAs. The spatial relationship can be conceptualised using different methods, such as fixed distance, k-nearest neighbours, travel time and contiguity. The conceptualisation of spatial relationship can be defined in the form of spatial weight matrix (Waller & Gotway, 2004).

The choice of the method is influenced by the spatial scale of the feature (LGA in terms of this thesis) and characteristics of the data. Initially, the fixed distance method was selected because this method was considered appropriate if there is a large variation between the regions (De Smith et al., 2007). In this method, the distance in which z-score peaks (11,500 metres in the datasets) is often considered the appropriate value for distance band. However, at that distance, 58 LGAs had no neighbours, which invalidates the statistical properties of the test (De Smith et al., 2007). Therefore, to ensure consistency in LGAs' number of neighbours, the k-nearest neighbours ($k = 8$) was chosen as the most appropriate method to conceptualise spatial relationship. This also ensures that equal numbers of LGAs are considered as neighbours for all LGAs in high- and low-burden areas for all selected outcome variables.

6.2.1 Test for global clustering

The Moran's test was applied to the selected outcome variables to test for spatial autocorrelation using 8-nearest neighbour as a conceptualisation of the spatial relationship among LGAs. The Moran's I method tests the null hypothesis of 'no clustering' against the alternative hypothesis of 'clustering'. The Moran's I statistic is presented as:

$$I = \frac{n \sum_{i=1}^m \sum_{j=1}^m w_{ij} (Z_i - \bar{Z})(Z_j - \bar{Z})}{\sum_{i=1}^m \sum_{j=1}^m w_{ij} \sum_{i=1}^m (Z_i - \bar{Z})^2}$$

Where, $Z_i = IR_i$, $\bar{Z} = 1/m \sum_{i=1}^m Z_i$, and w_{ij} is the $m \times m$ weight matrix defining the spatial relationship between an LGA i and its neighbour LGA j .

The Moran's I value ranges from -1 to 1, corresponding to:

- $I < 0$ = negative spatial autocorrelation (i.e., LGAs with high sport/leisure injury hospitalisation rates tend to be located next to LGAs with low sport/leisure injury hospitalisation rates)
- $I = 0$ = no spatial autocorrelation (accept the null hypothesis or no clustering)
- $I > 0$ = positive spatial autocorrelation (i.e., LGAs with high sport/leisure injury hospitalisation rates tend to be located next to LGAs with high sport/leisure injury hospitalisation rates. Alternatively, LGAs with low sport/leisure injury hospitalisation rates tend to be located next to LGAs with low sport/leisure injury hospitalisation rates).

Alternatively, the p-value and z-score returned by Moran's I test defines whether the null hypothesis (no clustering) can be rejected. The p-value is a probability that the observed pattern was formed by a random process. A small p-value means there is a small probability that the observed pattern is the result of a random process. The z-scores relate to a standard normal distribution (with mean zero and standard deviation of 1). Figure 6.1 shows the z-scores and p-values associated with normal distribution.

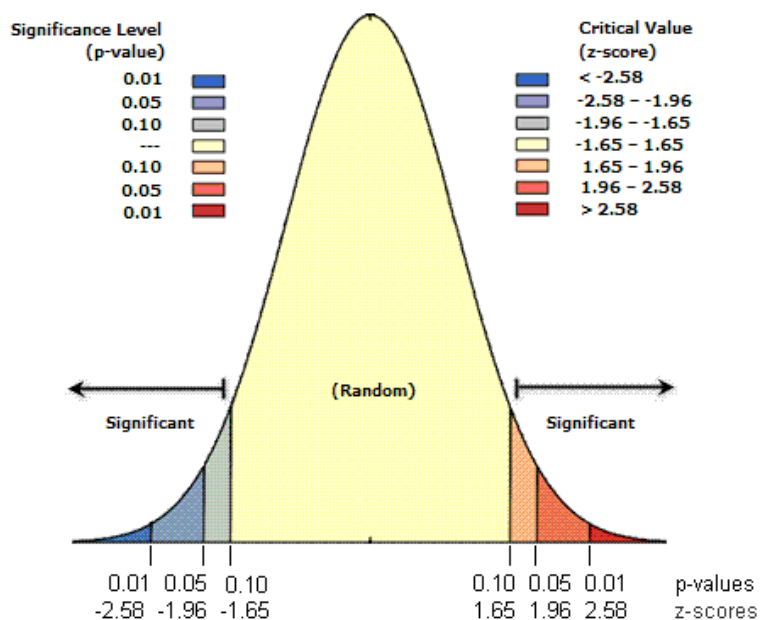


Figure 6.1: Z-score and p-value associated with the normal distribution

Adapted from (<http://pro.arcgis.com/en/pro-app/tool-reference/spatial-statistics/what-is-a-z-score-what-is-a-p-value.htm>)

6.2.2 Test for local clustering

The Getis-Ord G_i^* (Getis & Ord, 1992) method was used to identify local spatial clusters in the distribution of outcome variables using the 8-nearest neighbour as a conceptualisation of the spatial relationship among LGAs. The Getis-Ord G_i^* statistic is presented as:

$$G_i^* = \frac{\sum_j^n w_{i,j} x_j - \bar{X} \sum_{j=1}^n w_{i,j}}{S \sqrt{\frac{n \sum_{j=1}^n w_{i,j}^2 - (\sum_{j=1}^n w_{i,j})^2}{n-1}}}$$

Where, x_j is the IR of LGA j , $w_{i,j}$ is the spatial weight (spatial relationship) between LGA i and j and n = total number of LGA and:

$$\bar{X} = \frac{\sum_{j=1}^n x_j}{n},$$

$$S = \sqrt{\frac{\sum_{j=1}^n x_j^2}{n} - (\bar{X})^2}$$

The geospatial clusters identified using this method are divided into two categories: *hot* and *cold spot*. Statistically significant hot spots refer to areas in which LGAs with high rates are surrounded by other LGAs with high rates. Similarly, a cold spot refers to area in which LGAs with low rates are surrounded by other LGAs with low rates. The resulting G_i^* value, or z-score and p-value of the LGA, define whether an LGA is part of the hot spot, cold spot or not significant. The positive z-score of an LGA indicates that the LGA has a high rate and is surrounded by LGAs with high rates. The negative z-score of an LGA indicates that the LGA has a low rate and is surrounded by LGAs with low rates. Therefore, a positive z-score indicates hot spots or statistically significant clustering of high rates; a negative z-score indicates cold spots or statistically significant clustering of low rates. A z-score of nearly zero indicates no clustering.

The z-score of the LGA is calculated on the difference of the local sum of the LGA (sum of sport/leisure injury hospitalisation rates of the LGA and neighbouring LGAs) against the expected local sum (sum of sport/leisure injury hospitalisation rates of all LGAs). A

statistically significant z-score indicates the difference is too large to be the result of random chance. The intensity of the clustering is based on the z-score value, such that the larger or smaller a z-score is, the more intense the clustering of high or low rates.

The resulting z-scores are presented in choropleth maps for overall and sports specific injury hospitalisation rates to visualise the hot and cold spots. The hot and cold spots are presented by red and blue respectively. Darker colours represent a higher clustering intensity, while lighter colours represent low clustering intensity or no clustering. LGAs were identified as hot or cold spots based on the z-score of the LGA for overall and sport-specific injury hospitalisation rates. LGAs with a z-score greater or equal to 1.65 ($p = 0.10$) were considered hot spot LGAs and LGAs with a z-score smaller or equal to -1.65 ($p = 0.10$) were considered cold spot LGAs.

6.2.3 Demographic, place and injury characteristics of local clusters

The cases of hot and cold spots were extracted based on the selected demographic (e.g., sex and age) and injury characteristics (place of occurrence, injury type, body region and bed days). The number and proportion of cases by selected demographic and injury characteristics within the hot spot and cold spot were calculated. Ninety-five per cent CIs for these proportions were calculated using the Clopper-Pearson exact CI method (Clopper & Pearson, 1934) available in the PropCIs R-package (Scherer, 2016). Results are presented in the form of tables and graphs. The comparison between proportions of individual categories of demographic and injury-outcome characteristics are based on the reported CI of proportions.

6.3 Results

6.3.1 Overall sport/leisure injury hospitalisations

A map showing the EB smoothed sport/leisure injury hospitalisation rates was presented in Chapter 5 (see Figure 5.2). The Moran's I test ($I = 0.39$, z-score = 8.53) suggested spatial clustering of sport/leisure injury hospitalisations in Victoria. A map depicting the hot spot and cold spot identified by Getis-Ord G_i^* analysis of EB smoothed sport/leisure injury hospitalisation rates is presented in Figure 6.2. A hot spot was observed in south-west Victoria, whereas cold spots were observed in western Melbourne. Of the 104,271 injury hospitalisations, 6,473 cases (12 LGAs, 6.2% of the total sport/leisure injury hospitalisations)

resided in LGAs considered hot spots and 26,821 cases (17 LGAs, 25.7% of total sport/leisure injury hospitalisation) were in LGAs considered cold spots. The sport/leisure injury hospitalisation rates of hot and cold spots were 507.2/100,000 and 227.1/100,000 participants/year respectively.

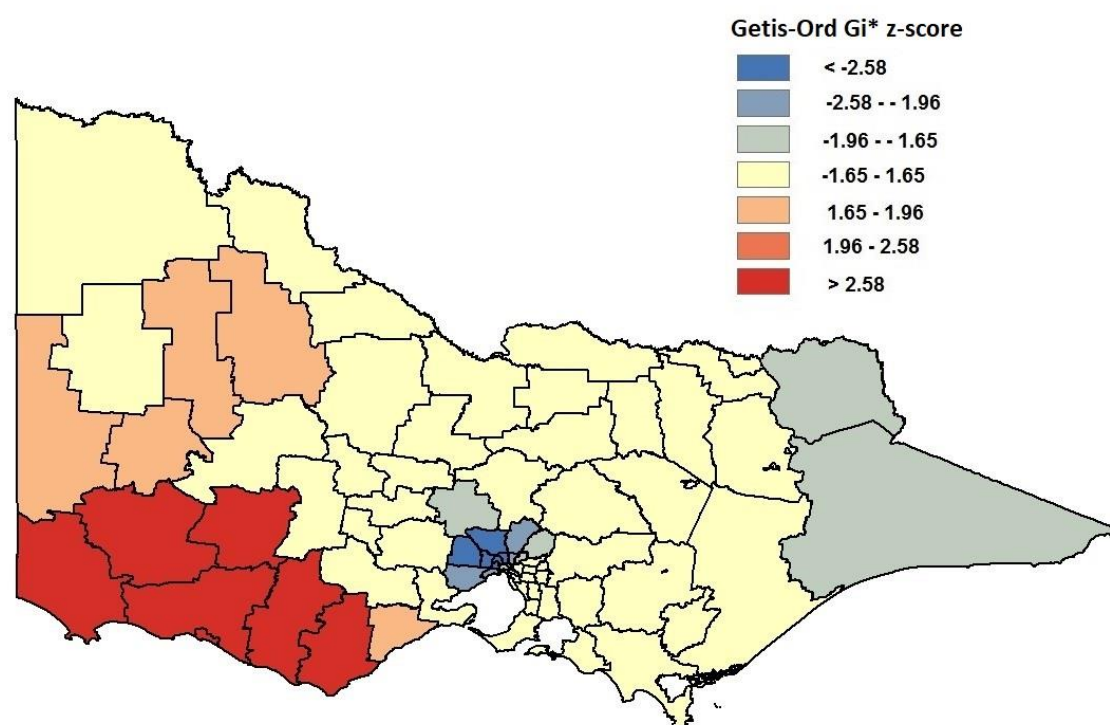


Figure 6.2: Map depicting the hot (z-score ≥ 1.65) and cold (z-score ≤ -1.65) spot regions of overall sport/leisure injury hospitalisation rates identified by Getis-Ord Gi* analysis

Table 6.1 presents the number and proportion of cases of sport/leisure injury hospitalisations by sex and age groups in hot and cold spot regions. There was a greater proportion of males than females in both hot ($n = 4,538$, 70.1% of total hot spot regions) and cold spots ($n = 20,208$, 75.3% of total cold spot regions). There was a significantly higher proportion of male sport/leisure injury hospitalisations in cold spot regions compared to male sport/leisure injury hospitalisation in hot spot regions (Table 6.1). A significantly higher proportion of female sport/leisure injury hospitalisations were observed in hot spot regions compared to female sport/leisure injury hospitalisations in cold spot regions (Table 6.1).

According to the age groups, the highest proportion of sport/leisure injury hospitalisations in hot and cold spot regions were people aged 15–24 years ($n = 2,016$, 31.2% of the region) and

25–44 years (n = 8,743, 32.6% of the region) respectively. The proportion of sport/leisure injury hospitalisations for people aged 0–14, 15–24 and over 65 years were significantly higher in hot spot regions compared to the proportion of sport/leisure injury hospitalisations in cold spots within the same age groups. The proportion of sport/leisure injury hospitalisations in people aged 25–44 years was significantly higher in cold spot regions compared to sport/leisure injury hospitalisation in people aged 25–44 years in cold spot regions. There was no significant difference in the proportion of sport/leisure injury hospitalisation in people aged 45–64 years between hot and cold spot regions.

Table 6.1: Number and proportion (95% CI) of overall sport/leisure injury hospitalisations by sex and age group in hot and cold spot regions

Demographic Variables	Categories	Hot spot (n = 12 LGAs)			Cold Spot (n = 17 LGAs)		
		n	%	95% CI	n	%	95% CI
Sex	Male	4,538	70.1	69.0–71.2	20,208	75.3	74.8–75.9
	Female	1,935	29.9	28.8–31	6,613	24.7	24.1–25.2
Age groups	0–14	2,011	31.1	29.9–32.2	6,938	25.9	25.3–26.4
	15–24	2,016	31.1	30.0–32.3	7,651	28.5	28.0–29.1
	25–44	1,516	23.4	22.4–24.5	8,743	32.6	32.0–33.2
	45–64	566	8.7	8.1–9.5	2,453	9.1	8.8–9.5
	65+	364	5.6	5.1–6.2	1,036	3.9	3.6–4.1

The number and proportion of sport/leisure injury hospitalisations in hot and cold spot regions by injury-outcome characteristics are presented in Table 6.2. Four place of occurrence categories accounted for 60.6 per cent and 44.9 per cent of total sport/leisure injury hospitalisations in hot and cold spot regions respectively. Within these categories, the highest proportion of sport/leisure injury hospitalisations in both hot and cold spot regions occurred in sports and athletics areas. There was a significant difference in the proportion of sport/leisure injury hospitalisation that occurred in ‘home’, ‘sports and athletics areas’ and ‘road street and highway’ categories between hot and cold spot regions. A significantly higher proportion of sport/leisure injury hospitalisations occurred in ‘sports and athletics areas’ and ‘home’ categories in hot spot regions compared to sport/leisure injury hospitalisations in respective categories in cold spot regions. In contrast, sport/leisure injury hospitalisations in the ‘road street and highway’ category were significantly higher in cold spot regions than they were in hot spot regions.

Five injury type categories accounted for 84.4 per cent and 89.3 per cent of total sport/leisure injury hospitalisations in hot and cold spot regions respectively. Within these categories, a greater proportion of sport/leisure injury hospitalisations in hot and cold spot areas were fractures. The proportion of fractures was significantly different in hot spots compared to cold spots. This was also the case for intracranial injuries. The proportion of fracture hospitalisations was significantly higher in cold spot regions than it was in hot spot regions. Additionally, the proportion of intracranial injury hospitalisations was significantly higher in hot spot regions than it was in cold spot regions.

Table 6.2: Number and proportion (95% CI) of overall sport/leisure injury hospitalisations by injury characteristics in hot and cold spot regions

Place and Injury Outcome Variables	Categories	Hot spot (n = 12 LGAs)			Cold spot (n = 17 LGAs)		
		n	%	95% CI	n	%	95% CI
Place of occurrences	Sports and athletic areas	2,748	42.5	41.2–43.7	10,407	38.8	38.2–39.4
	School, public buildings	399	6.2	5.6–6.8	1,683	6.3	6.0–6.6
	Home	443	6.8	6.2–7.5	1,257	4.7	4.4–4.9
	Road, street and highway	265	4.1	3.6–4.6	1,390	5.2	4.9–5.5
	Others*	2,618	40.4	39.2–41.7	12,084	45.1	44.5–45.7
Injury type	Fracture	3,375	52.1	50.9–53.4	15,975	59.6	59.0–60.1
	Dislocation, sprain and strain	899	13.9	13.1–14.8	3,770	14.1	13.6–14.5
	Open wound	461	7.1	6.5–7.8	1,652	6.2	5.9–6.5
	Intracranial injury	410	6.3	5.8–7.0	1,029	3.8	3.6–4.1
	Injury to muscle and tendon	319	4.9	4.4–5.5	1,512	5.6	5.4–5.9
	Others*	1,009	15.6	14.7–16.5	2,883	10.7	10.4–11.1
Body region injured	Knee and lower leg	1,296	20.0	19.1–21.0	6,910	25.8	25.2–26.3
	Elbow and forearm	1,298	20.1	19.1–21.0	4,436	16.5	16.1–17
	Head	1,182	18.3	17.3–19.2	4,134	15.4	15–15.9
	Wrist and hand	713	11.0	10.3–11.8	4,754	17.7	17.3–18.2
	Shoulder and upper arm	707	10.9	10.2–11.7	2,358	8.8	8.5–9.1
	Others*	1,277	19.7	18.8–20.7	4,229	15.8	15.3–16.2
Length of stay in hospital	< 2 days	4,667	72.1	71.0–73.2	18,378	68.5	68.0–69.1
	2–7 days	1,610	24.9	23.8–25.9	7,585	28.3	27.7–28.8
	8–30 days	183	2.8	2.4–3.3	817	3.0	2.8–3.3
	31–days	13	0.2	0.1–0.3	41	0.2	0.1–0.2

* Only the top four place categories and top five injury types and body region categories are presented; remaining cases are grouped together and presented as ‘others’.

Five body region categories accounted for 80.3 per cent and 84.2 per cent of total sport/leisure injury hospitalisations in hot and cold spot regions respectively. Within these categories, a greater proportion of sport/leisure injury hospitalisations in hot and cold spots were injuries to elbow, forearm, knee and lower leg respectively. The proportion of elbow, forearm, head, shoulder and upper arm injury hospitalisations was significantly higher in hot spot regions than it was in cold spot regions. The proportion of knee, lower leg, wrist and hand injury hospitalisations was significantly higher in cold spot regions than it was in hot spot regions.

According to the length of stay in hospital category, the greater proportion of sport/leisure injury hospitalisations in both hot and cold spot regions were for fewer than two days. A significant difference in the proportion of sport/leisure injury hospitalisations in hot and cold spot regions were observed for fewer than 2 and 2–7 days categories. The proportion of hospitalisations for fewer than 2 days and 2–7 days were significantly higher in hot and cold spot regions respectively.

6.3.2 Australian Football injury hospitalisations

A map showing the EB smoothed Australian Football injury hospitalisation rates was presented in Chapter 5 (see Figure 5.18). Moran's *I* test ($I = 0.62$, $z\text{-score} = 13.28$) suggests a spatial clustering of EB smoothed Australian Football injury hospitalisation rates in Victoria. A map depicting the hot and cold spots identified by Getis-Ord G_i^* analysis for Australian Football injury hospitalisation rates is presented in Figure 6.3. A hot and cold spot were observed in western and southern regions of Victoria respectively. Of the 14,489 Australian Football injury hospitalisations in Victoria, 2,041 (17 LGAs, 12.8% of Australian Football injury hospitalisations) cases resided in LGAs considered hot spots, while 8,278 (33 LGAs, 33.1% of Australian Football injury hospitalisations) cases resided in LGAs considered cold spots with the rate of 3,701.6/100,000 and 1,035.3/100,000 participants respectively.

Table 6.3 presents the number and proportion of Australian Football injury hospitalisations by sex and age for hot and cold spot regions. There was a greater proportion of male Australian Football injury hospitalisations in both hot spots ($n = 2,041$, 98.8% of region total) and cold spots ($n = 8,003$, 96.7% of region total) compared to female hospitalisation rates. A significant difference was observed in the proportion of male and female Australian Football injury hospitalisations between hot and cold spot regions (Table 6.3). A higher proportion of

male Australian Football injury hospitalisations were observed in hot spot regions compared to male Australian Football injury hospitalisations in cold spot regions (Table 6.3). Further, there was a higher proportion of female Australian Football injury hospitalisations in cold spot regions than there was in hot spot regions.

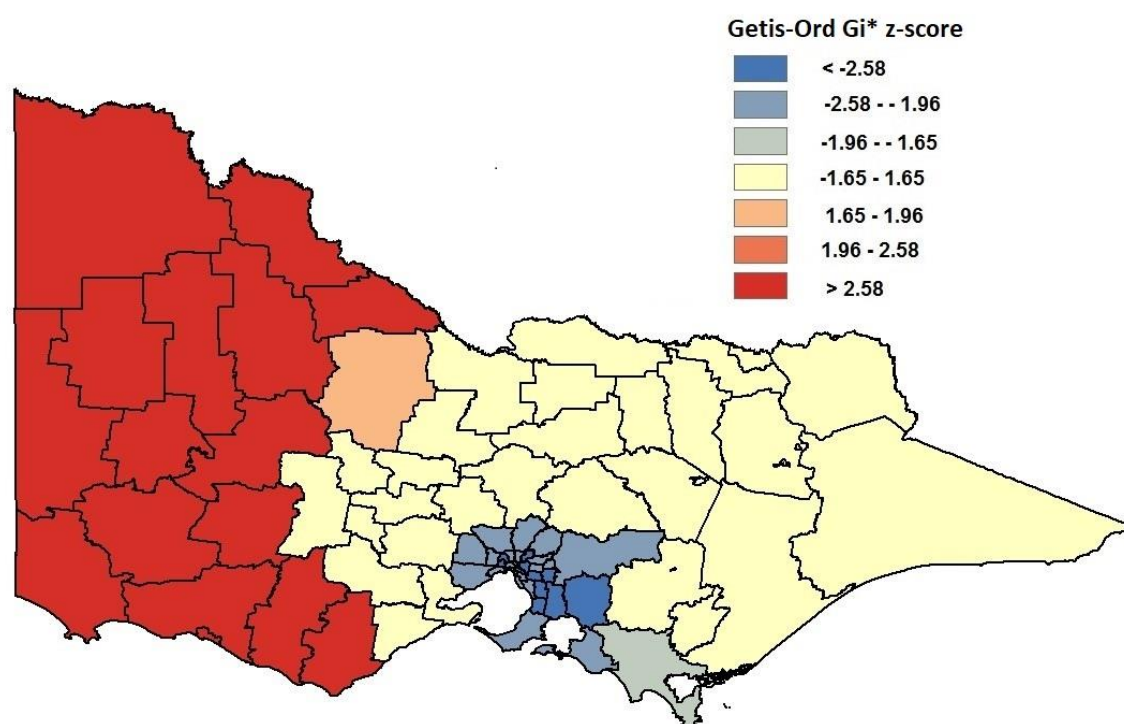


Figure 6.3: Map depicting the hot (z-score ≥ 1.65) and cold (z-score ≤ -1.65) spot regions identified by Getis-Ord Gi* analysis of Australian Football injury hospitalisation rates

In terms of age group, the greater proportion of Australian Football injury hospitalisations in hot spots ($n = 1,094$, 53.6% of region total) and cold spots ($n = 4,096$, 49.5% of region total) were people aged 15-24 years. A significant difference was observed in the proportion of Australian Football injury hospitalisations in people aged 0-14 and 15-24 years between hot and cold spot regions. Within these age groups, the proportion of Australian Football injury hospitalisations in people aged 0-14 years was higher in cold spot regions than it was in hot spot regions. The proportion of Australian Football injury hospitalisations in people aged 15-24 years was higher in hot spot regions than it was in cold spot regions.

Table 6.4 presents the number and proportion of Australian Football injury hospitalisations by injury-outcome characteristics in hot and cold spot regions. Four place of occurrence categories accounted for 89.7 per cent and 78.4 per cent of total Australian Football injury

hospitalisations in hot and cold spot regions respectively. Within these place categories, the highest proportion of Australian Football injury hospitalisations in hot spot (n = 1,770, 86.7% of region total) and cold spot (n = 6,171, 74.5% of region total) regions were due to injuries that occurred at sport and athletics areas. There was a significant difference in the proportion of Australian Football injury hospitalisations that occurred at sports and athletics areas between hot and cold spot regions, with significantly higher rates observed in hot spot regions.

Table 6.3: Number and proportion of Australian Football injury hospitalisations by sex and age group in hot and cold spot regions

Demographic Variables	Categories	Hot spot (n = 17 LGAs)			Cold spot (n = 33 LGAs)		
		n	%	95% CI	n	%	95% CI
Sex	Male	2,016	98.8	98.2–99.2	8,003	96.7	96.3–97.1
	Female	25	1.2	0.8–1.8	275	3.3	2.9–3.7
Age groups	0–14	318	15.6	14.0–17.2	1,709	20.6	19.8–21.5
	15–24	1,094	53.6	51.4–55.8	4,096	49.5	48.4–50.6
	25–44	608	29.8	27.8–31.8	2,325	28.1	27.1–29.1
	45–64	20	1.0	0.6–1.5	137	1.7	1.4–2.0
	65+	*	*	*	11	0.1	0.1–0.2

* Value less than five in column (n) is replaced with *

Five injury type categories accounted for 85.0 per cent and 89.1 per cent of total Australian Football injury hospitalisations in hot and cold spot regions respectively. Within these categories, the highest proportion of Australian Football injury hospitalisations in hot spots (n = 1,019, 49.9% of region total) and cold spots (n = 4,967, 60.0% of region total) were fractures. There was a significant difference in the proportion of injury hospitalisations due to dislocation, sprain, strain and fractures between hot and cold spot regions. The proportion of injury hospitalisations due to dislocation, sprain and strain was significantly higher in hot spot regions. The proportion of fractures was higher in cold spot regions compared to the proportion in hot spot regions.

Five body region categories accounted for 84.0 per cent (n = 1715) and 87.5 per cent (n = 7245) of total Australian Football injury hospitalisations in hot and cold spot regions respectively. Within these categories, the highest proportion of Australian Football injury hospitalisations in hot spot (n = 477, 23.4% of region total) and cold spot (n = 2,061, 24.9% of region total) regions were knee, lower leg, wrist and hand injuries respectively. The

proportion of shoulder, upper arm, wrist and hand injury hospitalisations was significantly different in hot and cold spot regions. A significantly higher proportion of shoulder, upper arm, wrist and hand injury hospitalisations was observed in hot and cold spot regions respectively.

Table 6.4: Number and proportion of Australian Football injury hospitalisations by selected injury characteristics in hot and cold spot regions

Place and Injury Outcome Variables	Categories	Hot spot (n = 17 LGAs)			Cold spot (n = 33 LGAs)		
		n	%	95% CI	n	%	95% CI
Place of occurrences	Sports and athletic areas	1,770	86.7	85.2–88.2	6,171	74.5	73.6–75.5
	School, public buildings	51	2.5	1.9–3.3	274	3.3	2.9–3.7
	Home	9	0.4	0.2–0.8	35	0.4	0.3–0.6
	Road, street and highway	*	*	*	7	0.1	0–0.2
	Others*	210	10.3	9.0–11.7	1,791	21.6	20.8–22.5
Injury type	Fracture	1,019	49.9	47.7–52.1	4,967	60.0	58.9–61.1
	Dislocation, sprain and strain	457	22.4	20.6–24.3	1,336	16.1	15.4–16.9
	Intracranial injury	168	8.2	7.1–9.5	618	7.5	6.9–8.1
	Injury to muscle and tendon	55	2.7	2.0–3.5	280	3.4	3.0–3.8
	Open wound	35	1.7	1.2–2.4	177	2.1	1.8–2.5
	Others*	307	15.0	13.5–16.7	900	10.9	10.2–11.6
Body region injured	Knee and lower leg	477	23.4	21.5–25.3	1,718	20.8	19.9–21.6
	Elbow and forearm	274	13.4	12.0–15.0	1,072	12.9	12.2–13.7
	Wrist and hand	297	14.6	13.0–16.2	2,061	24.9	24.0–25.8
	Head	443	21.7	19.9–23.6	1,841	22.2	21.3–23.2
	Shoulder and upper arm	224	11.0	9.7–12.4	553	6.7	6.2–7.2
	Others*	326	16.0	14.4–17.6	1,033	12.5	11.8–13.2
Length of stay in hospital	< 2 days	1,609	78.8	77–80.6	6,454	78.0	77.1–78.9
	2–7 days	414	20.3	18.6–22.1	1,747	21.1	20.2–22
	8–30 days	15	0.7	0.4–1.2	74	0.9	0.7–1.1
	31+ days	*	*	*	*	*	*

* Only the top four place setting categories and top five injury types and body region categories are presented; remaining cases are grouped together and presented as ‘others’.

* Value less than five in column (n) is replaced with *

According to the length of stay category, the highest proportion of Australian Football injury hospitalisations in hot spot (n = 1,609, 78.8% of region total) and cold spot (n = 6,454, 78.0% of region total) regions was fewer than two days. A significant difference in the proportion of

Australian Football injury hospitalisations for under two and 2–7 days categories was observed between hot and cold spot regions. Australian Football injury hospitalisations in these categories was significantly higher in hot and cold spot regions respectively.

6.3.3 Soccer injury hospitalisations

A map showing the EB smoothed soccer injury hospitalisation rates was presented in Chapter 5 (see Figure 5.20). Moran's I ($I = 0.66$, $z\text{-score} = 14.04$) illustrates spatial clustering of soccer injury hospitalisation rates in Victoria. A map depicting the hot and cold spot regions identified by Getis-Ord G_i^* analysis for soccer injury hospitalisations is presented in Figure 6.4. The clustering of high and low soccer injury hospitalisation rates was observed in metropolitan and outer regional parts of Victoria respectively. Of the 6,195 soccer injury hospitalisations, 5,174 (29 LGAs, 83.5% of total soccer injury hospitalisation) resided in LGAs considered hot spot regions, while 376 (30 LGAs, 6.1% of total soccer injury hospitalisation) resided in LGAs considered cold spot regions with rates of 718.8/100,000 and 291.3/100,000 participants respectively.

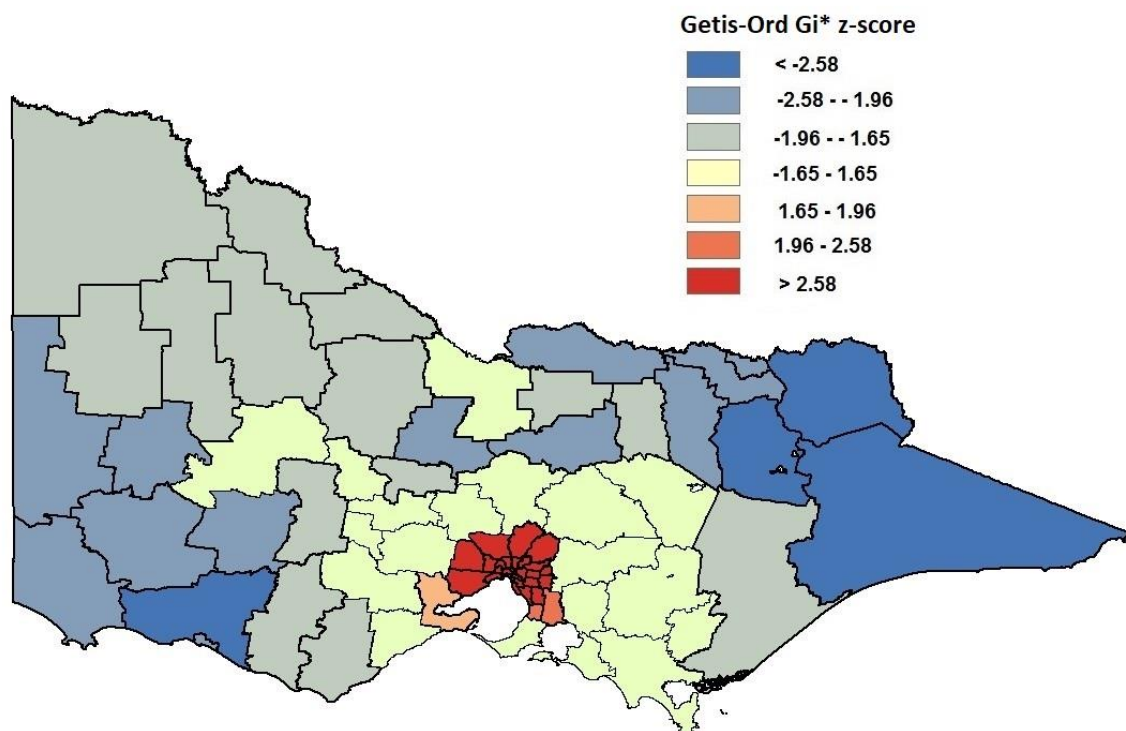


Figure 6.4: Map depicting the hot ($z\text{-score} \geq 1.65$) and cold ($z\text{-score} \leq -1.65$) spot regions identified by Getis-Ord G_i^* analysis of soccer injury hospitalisations

The proportion of soccer injury hospitalisations by sex and age group for hot and cold spot regions is presented in Table 6.5. There was a greater proportion of male soccer injury hospitalisations than female soccer injury hospitalisations in both hot spot (n = 4,652, 89.9% of region total) and cold spot (n = 288, 76.6% of region total) regions. There was a significant difference in the proportion of male and female soccer injury hospitalisations between hot and cold spot regions (Table 6.5). The proportion of male soccer injury hospitalisations was significantly higher in hot spot regions than it was in cold spot regions (Table 6.5).

In terms of age group, the highest proportion of soccer injury hospitalisations in hot spot (n = 1,944, 37.6% of region total) and cold spot (n = 138, 36.7% of region total) regions was in people aged 25–44 and 15–24 years respectively. There was a significant difference in the proportion of soccer injury hospitalisations in people aged 0–14 and 25–44 years between hot and cold spot regions. The proportion of soccer injury hospitalisations in people aged 0–14 and 25–44 years was significantly higher in cold and hot spot regions respectively.

Table 6.5: Number and proportion of soccer injury hospitalisations by sex and age group for hot and cold spot regions

Demographic Variables	Categories	Hot spot (n = 29 LGAs)			Cold spot (n = 30 LGAs)		
		n	%	95% CI	n	%	95% CI
Sex	Male	4,652	89.9	89.1–90.7	288	76.6	72.0–80.8
	Female	522	10.1	9.3–10.9	88	23.4	19.2–28.0
Age groups	0–14	1,129	21.8	20.7–23.0	130	34.6	29.8–39.6
	15–24	1,833	35.4	34.1–36.7	138	36.7	31.8–41.8
	25–44	1,944	37.6	36.3–38.9	91	24.2	20.0–28.9
	45–64	249	4.8	4.2–5.4	16	4.3	2.5–6.8
	65+	19	0.4	0.2–0.6	*	*	*

* Value less than five in column (n) is replaced with *

Table 6.6 presents the number and proportion of soccer injury hospitalisations by injury characteristics in hot and cold spot regions. Four place of occurrences accounted for 69.5 per cent and 76.6 per cent of total soccer injury hospitalisations in hot and cold spot regions respectively. Within place of occurrence categories, the highest proportion of soccer injury hospitalisations in hot spots (n = 3,202, 61.9% of region total) and cold spots (n = 244, 64.9% of region total) occurred in sports and athletics areas. The only significant difference was the proportion of soccer injury hospitalisations in school and public buildings between hot and

cold spot regions, with a significantly higher proportion of hospitalisations observed in cold spot regions compared to hot spot regions.

The five most common types of injuries accounted for 93.9 per cent and 87.8 per cent of total soccer injury hospitalisations in hot and cold spot regions respectively. Within these injury types, the highest proportion of soccer injury hospitalisations in hot spot (n = 3,025, 58.5% of region total) and cold spot (n = 207, 55.9%) regions were fractures. No significant difference was observed in the proportion of soccer injury hospitalisations by injury type categories between hot and cold spot regions.

Table 6.6: Number and proportion of soccer injury hospitalisations by selected categories of injury characteristics in hot and cold spot regions

Place and Injury Outcome Variables	Categories	Hot spot (n = 29 LGAs)			Cold spot (n = 30 LGAs)		
		n	%	95% CI	n	%	95% CI
Place of occurrences	Sports and athletic areas	3,202	61.9	60.5–63.2	244	64.9	59.8–69.7
	School, public buildings	335	6.5	5.8–7.2	41	10.9	7.9–14.5
	Home	53	1.0	0.8–1.3	*	*	*
	Road, street and highway	6	0.1	0–0.3	*	*	*
	Others	1,578	30.5	29.2–31.8	88	23.4	19.2–28
Injury type	Fracture	3,025	58.5	57.1–59.8	212	56.4	51.2–61.5
	Dislocation, sprain and strain	1,093	21.1	20.0–22.3	72	19.1	15.3–23.5
	Intracranial injury	169	3.3	2.8–3.8	15	4.0	2.2–6.5
	Injury to muscle and tendon	457	8.8	8.1–9.6	21	5.6	3.5–8.4
	Open wound	113	2.2	1.8–2.6	10	2.7	1.3–4.8
	Others	317	6.1	5.5–6.8	46	12.2	9.1–16
Body region injured	Knee and lower leg	2,320	44.8	43.5–46.2	156	41.5	36.5–46.7
	Elbow and forearm	838	16.2	15.2–17.2	92	24.5	20.2–29.1
	Wrist and hand	646	12.5	11.6–13.4	21	5.6	3.5–8.4
	Head	671	13	12.1–13.9	47	12.5	9.3–16.3
	Shoulder and upper arm	195	3.8	3.3–4.3	13	3.5	1.9–5.8
	Others	504	9.7	8.9–10.6	47	12.5	9.3–16.3
Length of stay in hospital	< 2 days	3,619	69.9	68.7–71.2	278	73.9	69.2–78.3
	2–7 days	1,481	28.6	27.4–29.9	95	25.3	21.0–30.0
	8–30 days	73	1.4	1.1–1.8	*	*	*
	31+ days	*	*	*	*	*	*

* Only the top four place setting categories and top five injury types and body region categories are presented; remaining cases are grouped together and presented as ‘others’.

* Value less than five in column (n) is replaced with *

Five body region categories accounted for 90.3 per cent and 87.5 per cent of total soccer injury hospitalisations in hot spot and cold spot regions respectively. Within these categories, the highest proportion of soccer injury hospitalisations in hot spot (45.25%) and cold spot (38.24%) regions were injuries to the knee and lower leg. There was a significant difference in the proportion of elbow, forearm, wrist and hand injury hospitalisations between hot and cold spot regions. The proportion of elbow, forearm, wrist and hand injury hospitalisations were significantly higher in cold and hot spot regions respectively.

The greater proportion of soccer injury hospitalisations in hot (69.9%) and cold spot (73.9%) regions were durations of fewer than two days. The proportions of soccer injury hospitalisations for under two days and 2–7 days were significantly different between hot and cold spot regions. A significantly higher proportion of soccer injury hospitalisations for fewer than 2 days and 2–7 days were observed in hot and cold spot regions respectively.

6.3.4 Basketball injury hospitalisations

A map showing EB smoothed basketball injury hospitalisations rates is presented in Figure 5.22. Moran's *I* test ($I = 0.41$, $z\text{-score} = 8.84$) indicated a spatial clustering of LGAs with high basketball injury hospitalisation rates and low basketball injury hospitalisation rates. A map depicting the hot and cold spots identified by the Getis-Ord G_i^* analysis of basketball injury hospitalisations is presented in Figure 6.5. The clustering of high and low basketball injury hospitalisation rates was observed in central and northern Victoria respectively. Of the 5,415 basketball injury hospitalisations in Victoria, 2,392 (15 LGAs, 40.6% of total basketball injury hospitalisations) resided in LGAs considered a hot spot and 115 (12 LGAs, 2.7% of total basketball injury hospitalisations) resided in LGAs considered as cold spot regions with the rate of 409.9/100,000 and 122.7/100,000 participants respectively.

The number and proportion of basketball injury hospitalisations by sex and age group in hot and cold spot regions are presented in Table 6.7. There was a greater proportion of male basketball injury hospitalisations compared to female basketball injury hospitalisations in both hot spot ($n = 1,666$, 75.9% of region total) and cold spot ($n = 78$, 67.8% of region total) regions. There was no significant difference in the proportion of male and female basketball injury hospitalisations between hot and cold spot regions (Table 6.7).

The highest proportion of basketball injury hospitalisations in hot spot regions was in people aged 15–24 years (n = 827, 37.7% of region total), while in cold spot regions it was in people aged 25–44 years (n = 38, 33.0% of region total). No significant difference was observed in the proportions of basketball injury hospitalisations by age group between hot and cold spot regions.

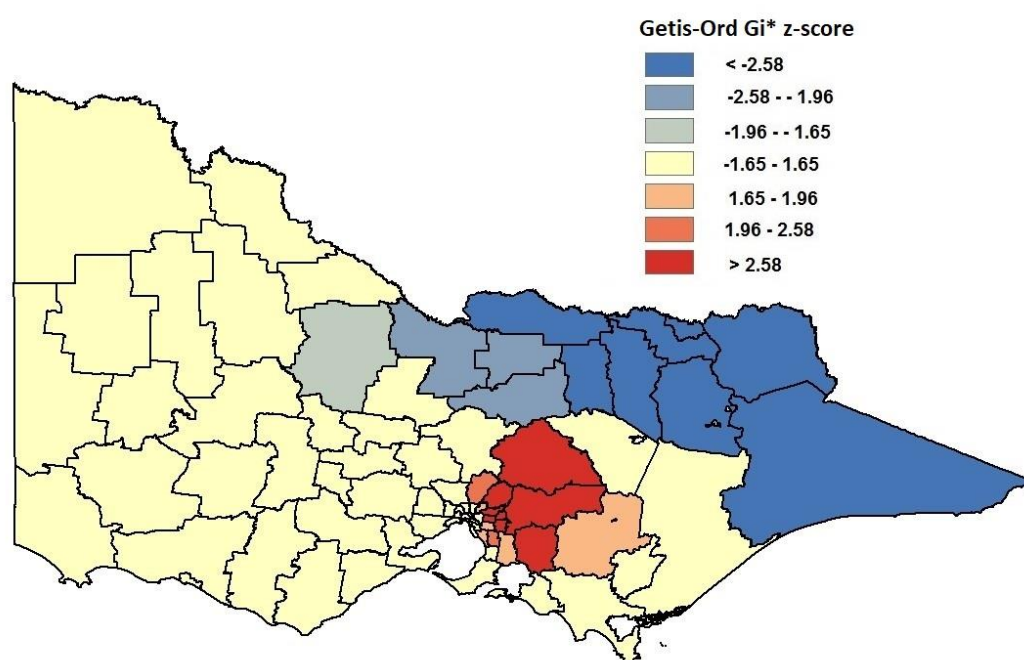


Figure 6.5: Map depicting the hot (z-score ≥ 1.65) and cold (z-score ≤ -1.65) spot regions identified by Getis-Ord Gi* analysis of basketball injury hospitalisations in Victoria

Table 6.7: Number and proportion of basketball injury hospitalisations by sex and age groups in hot and cold spot regions

Demographic Variables	Categories	Hot spot (n = 15 LGAs)			Cold spot (n = 12 LGAs)		
		n	%	95% CI	n	%	95% CI
Sex	Male	1,817	76.0	74.2–77.7	78	67.8	58.5–76.2
	Female	575	24.0	22.3–25.8	37	32.2	23.8–41.5
Age groups	0–14	575	24.0	22.3–25.8	33	28.7	20.6–37.9
	15–24	894	37.4	35.4–39.3	36	31.3	23.0–40.6
	25–44	801	33.5	31.6–35.4	38	33.0	24.6–42.4
	45–64	119	5.0	4.1–5.9	8	7.0	3.1–13.2
	65+	*	*	*	*	*	*

* Value less than five in column (n) is replaced with *

The number and proportion of basketball injury hospitalisations by injury characteristics in hot and cold spot regions are presented in Table 6.8. Four place of occurrence categories accounted for 67.4 per cent and 73.0 per cent of total basketball injury hospitalisations in hot and cold spot regions respectively. Within these categories, the highest proportion of basketball injury hospitalisations in hot (n = 1,477, 61.7% of region total) and cold spot (n = 82, 71.3% of region total) regions occurred at sports and athletics areas. No significant difference was observed in the proportions of basketball injury hospitalisations by place of occurrence in hot and cold spot regions.

Five injury type categories accounted for 94.1 per cent and 89.6 per cent of total basketball injury hospitalisations in hot and cold spot regions. Within these categories, the highest proportion of basketball injury hospitalisations in hot spot (n = 1,367, 57.1% of region total) and cold spot (n = 58, 50.4% of region total) regions were fractures. No significant difference was observed in the proportions of basketball injury hospitalisations by injury type categories between hot and cold spot regions.

Five body region categories accounted for 90.7 per cent and 87.0 per cent of total basketball injury hospitalisations in hot and cold spot regions. Within these categories, there was a higher proportion of knee and lower leg injury hospitalisations in hot (n = 839, 35.1% of region total) and cold spot (n = 43, 37.4% of region total) regions. There was a significant difference in the proportion of head, elbow and forearm injury hospitalisations between hot and cold spot regions. The proportion of head, elbow and forearm injury hospitalisations were higher in hot and cold spot regions respectively.

According to the length of stay category, 79.2 per cent and 84.3 per cent of total basketball injury hospitalisations in hot and cold spot regions were for fewer than two days. Other length of stay categories accounted for only a small proportion of total basketball injury hospitalisations in hot and cold spot regions. No significant difference was observed in the proportion of length of stay categories between hot and cold spot regions.

Table 6.8: Number and proportion of basketball injury hospitalisations by injury characteristics in hot and cold spot regions

Place and Injury Outcome Variables	Categories	Hot spot (n = 15 LGAs)			Cold spot (n = 12 LGAs)		
		n	%	95% CI	n	%	95% CI
Place of occurrences	Sports and athletic areas	1,477	61.7	59.8–63.7	82	71.3	62.1–79.4
	School, public buildings	115	4.8	4.0–5.7	*	*	*
	Home	18	0.8	0.4–1.2	*	*	*
	Road, street and highway	*	*	*	*	*	*
	Others*	780	32.6	30.7–34.5	31	27.0	19.1–36
Injury type	Fracture	1,367	57.1	55.1–59.1	58	50.4	41.0–59.9
	Dislocation, sprain and strain	523	21.9	20.2–23.6	22	19.1	12.4–27.5
	Injury to muscle and tendon	272	11.4	10.1–12.7	21	18.3	11.7–26.5
	Intracranial injury	48	2.0	1.5–2.7	*	*	*
	Open wound	41	1.7	1.2–2.3	*	*	*
	Others*	141	5.9	5.0–6.9	12	10.4	5.5–17.5
Body region injured	Knee and lower leg	839	35.1	33.2–37.0	43	37.4	28.5–46.9
	Elbow and forearm	363	15.2	13.8–16.7	30	26.1	18.3–35.1
	Wrist and hand	592	24.7	23.0–26.5	17	14.8	8.9–22.6
	Head	307	12.8	11.5–14.2	6	5.2	1.9–11
	Shoulder and upper arm	69	2.9	2.3–3.6	*	*	*
	Others*	222	9.3	8.1–10.5	15	13.0	7.5–20.6
Length of stay in hospital	< 2 Days	1,895	79.2	77.5–80.8	97	84.3	76.4–90.5
	2–7 Days	470	19.6	18.1–21.3	17	14.8	8.9–22.6
	8–30 Days	26	1.1	0.7–1.6	*	*	*
	31+ Days	*	*	*	*	*	*

* Only the top four place setting categories and top five injury types and body region categories are presented; remaining cases are grouped together and presented as ‘others’.

* Value less than five in column (n) is replaced with *

6.3.5 Cricket injury hospitalisations

A map showing EB smoothed cricket injury hospitalisation rates was presented in Figure 5.24. Moran’s I test ($I = 0.21$, z -score = 4.90) indicated a spatial clustering of high and low cricket injury hospitalisation rates in Victoria. A map depicting the clusters of high cricket injury hospitalisation rates (hot spots) and low cricket injury hospitalisation rates (cold spots) identified by Getis-Ord G_i^* analysis for cricket injury hospitalisations is presented in Figure 6.6. The clustering of high and low cricket injury hospitalisation rates was observed in south-west and north-east Victoria. Of the 2607 cricket injury hospitalisations, 150 (10 LGAs, 5.7% of total cricket injury hospitalisations) resided in LGAs considered hot spot regions and 343

(14 LGAs, 14.3% of total cricket injury hospitalisations) resided in LGAs considered cold spot regions with the rate of 465.5/100,000 and 194.6/100,000 participants respectively.

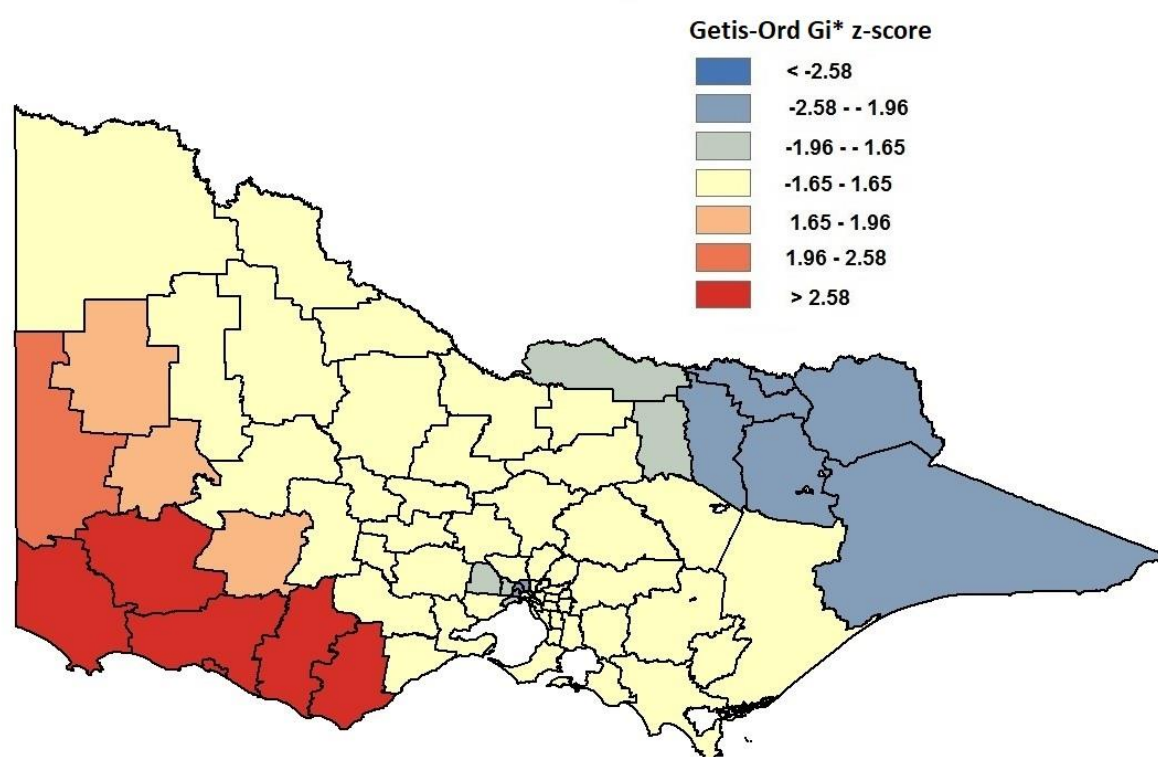


Figure 6.6: Map depicting the hot (z-score ≥ 1.65) and cold (z-score ≤ -1.65) spot regions identified by Getis-Ord Gi* analysis of cricket injury hospitalisations

The proportion of cricket injury hospitalisations by sex and age group in hot and cold spot regions is presented in Table 6.9. Male cricket injury hospitalisations in hot and cold spot regions accounted for 96 per cent and 95.3 per cent of total cricket injury hospitalisations within those regions. There was no significant difference in the proportion of male and female cricket injury hospitalisations between hot and cold spot regions (Table 6.9).

There was a greater proportion of cricket injury hospitalisations in people aged 25–44 years in hot spot ($n = 61$, 40.7%) and cold spot ($n = 169$, 49.3%) regions respectively. There was no significant difference observed in the proportions of cricket injury hospitalisations by age group between hot and cold spot regions.

The number and proportion of cases of cricket injury hospitalisations by injury characteristics in hot and cold spot regions is presented in Table 6.10. Four place of occurrence categories accounted for 64.7 per cent and 56.4 per cent of total cricket injury hospitalisations in hot and cold spot regions respectively. The sports and athletics areas category accounted for 58.7 per

cent and 51 per cent of total cricket injury hospitalisations in hot and cold spot regions respectively. There was no significant difference in proportion for place categories between hot and cold spot regions.

Five injury types accounted for 88.7 per cent and 92.3 per cent of total cricket injury hospitalisations in hot and cold spot regions respectively. Fractures accounted for 48.7 per cent and 62.4 per cent of total cricket injury hospitalisations in hot and cold spot regions, respectively. There was no significant difference in the proportion for injury types between hot and cold spot regions.

Table 6.9: Number and proportion of cricket injury hospitalisations by sex and age group in hot and cold spot regions

Demographic Variables	Categories	Hot spot (n = 10 LGAs)			Cold spot (n = 14 LGAs)		
		n	%	95% CI	n	%	95% CI
Sex	Male	144	96.0	91.5–98.5	327	95.3	92.5–97.3
	Female	6	4.0	1.5–8.5	16	4.7	2.7–7.5
Age groups	0–14	24	16.0	10.5–22.9	43	12.5	9.2–16.5
	15–24	41	27.3	20.4–35.2	92	26.8	22.2–31.8
	25–44	61	40.7	32.7–49.0	169	49.3	43.9–54.7
	45–64	20	13.3	8.3–19.8	35	10.2	7.2–13.9
	65+	*	*	*	*	*	*

* Value less than five in column (n) is replaced with *

Five body region categories accounted for 88.7 per cent and 90.7 per cent of total cricket injury hospitalisations in hot and cold spot regions respectively. Within these categories, the highest proportion of cricket injury hospitalisations in hot spot (n = 43, 28.7% of region total) and cold spot (n = 142, 41.4% of region total) regions was observed for the head, wrist and hand categories respectively. The only significant difference in proportion between hot and cold spot regions was observed in the wrist and hand category with a greater proportion in cold spot regions.

According to length of stay categories, 85.3 per cent and 80.5 per cent of total cricket injury hospitalisations in hot and cold spot regions were for under two days. No significant difference was observed in the proportions of cricket injury hospitalisations for length of stay categories between hot spot and cold spot regions.

Table 6.10: Number and proportion of cricket injury hospitalisations by injury characteristics in hot and cold spot regions

Place and Injury Outcome Variables	Categories	Hot spot (n = 10 LGAs)			Cold spot (n = 14 LGAs)		
		n	%	95% CI	n	%	95% CI
Place of occurrences	Sports & athletic areas	88	58.7	50.3–66.6	175	51.0	45.6–56.4
	Road, street & highway	*	*	*	*	*	*
	School, public buildings	*	*	*	11	3.2	1.6–5.7
	Home	*	*	*	11	3.2	1.6–5.7
	Others*	53	35.3	27.7–43.5	146	42.6	37.3–48
Injury type	Fracture	73	48.7	40.4–57.0	214	62.4	57.0–67.5
	Dislocation, sprain and strain	28	18.7	12.8–25.8	52	15.2	11.5–19.4
	Intracranial injury	6	4.0	1.5–8.5	7	2.0	0.8–4.2
	Injury to muscle and tendon	17	11.3	6.7–17.5	31	9.0	6.2–12.6
	Open wound	9	6.0	2.8–11.1	9	2.6	1.2–4.9
	Others*	17	11.3	6.7–17.5	30	8.7	6–12.3
Body region injured	Knee and lower leg	29	19.3	13.3–26.6	70	20.4	16.3–25.1
	Elbow and forearm	10	6.7	3.2–11.9	25	7.3	4.8–10.6
	Wrist and hand	41	27.3	20.4–35.2	142	41.4	36.1–46.8
	Head	43	28.7	21.6–36.6	56	16.3	12.6–20.7
	Shoulder and upper arm	10	6.7	3.2–11.9	18	5.2	3.1–8.2
	Others*	17	11.3	6.7–17.5	32	9.3	6.5–12.9
Length of stay in hospital	< 2 days	128	85.3	78.6–90.6	276	80.5	75.9–84.5
	2–7 days	19	12.7	7.8–19.1	62	18.1	14.1–22.6
	8–30 days	*	*	*	*	*	*
	31+ days	*	*	*	*	*	*

* Only the top four place setting categories and top five injury types and body region categories are presented; remaining cases are grouped together and presented as ‘others’.

* Value less than five in column (n) is replaced with *

6.4 Conclusions

In this chapter, clustering and cluster detection methods were used to examine the geographical variation of sport/leisure injury hospitalisations across Victorian LGAs. The null hypothesis was that the sport/leisure injury hospitalisation rates by LGA are randomly distributed. However, the use of clustering methods indicated that the high and low sport/leisure injury hospitalisation rates of LGA are clustered. To identify the location of these clusters, a cluster detection method was used, which showed evidence of clustering of

high rates in regional south-west Victoria. Previous studies conducted in Victoria and NSW using the traditional approach demonstrated higher rates of sport/leisure injury hospitalisations in regional areas (Finch & Boufous, 2009; Lam, 2005). The application of geospatial methods in this study is a novel approach to extend previous research. The findings of this study identify the specific regions with higher sport/leisure injury rates within regional Victoria. The knowledge has been further extended by examining the injury rates associated with specific sports in Victoria. The findings have highlighted that the location of geospatial clusters of high and low rates varies. For example, high and low rates of soccer injury hospitalisations are clustered in metropolitan and regional LGAs respectively, while the inverse pattern was observed in Australian Football injury hospitalisation rates. The different location of high and low geospatial clusters by specific sports indicate that the risk of injury from specific sports most likely varies by geographic location.

The characteristics of the identified high and low clusters were further investigated. Findings revealed a significant difference in the proportion of hospitalisations by some key categories of demographic, place and injury outcome variables. These differences in the proportion of injury hospitalisations within hot and cold spots is important to understand to better target injury preventive efforts. This study presents new knowledge about communities or populations that are consistently at greater risk to underpin policy development and prioritisation of injury prevention efforts.

The reasons for the observed high and low clusters for specific sports are unclear without further investigation. However, the difference in observed location of clusters is most likely due, at least in part, to the difference in sports delivery factors and medical facilities in those regions, such as safe sports facilities, use of protective equipment, coaches and hospitals (Bahr & Holme, 2003; Finch et al., 2003; Finch & Boufous, 2009). Other factors that could contribute are SES differences, distribution of population diversity (e.g., Aboriginal population, non-English speaking background and education) across the regions. Studies have demonstrated that these factors are associated with other injury-cause categories such as road traffic, workplace and falls. Thus, they are critical to understand injury prevention (Anikeeva et al., 2010; Bell & Schuurman, 2010; Cubbin, LeClere & Smith, 2000b; Trajkovski & Loosemore, 2006). The next chapter will focus on understanding the relationship between sport/leisure injury hospitalisation rates and neighbourhood characteristics, such as SES, education and population diversity using geospatial analysis methods.

Chapter 7: Investigating the Relationship Between Neighbourhood Characteristics and Sport/Leisure Injury Hospitalisations Using Geospatial Analysis Methods

7.1 Introduction

It has been shown that neighbourhood characteristics such as socio-economic, demographic and diversity factors are associated with injury risk in broad injury epidemiological studies (Potter et al., 2005; Viner et al., 2012). However, the level and nature of these association varies depending on the population under study, type of injury and examined neighbourhood characteristics (Cubbin & Smith, 2002; Pickett et al., 2005; Potter et al., 2005). The injuries, by definition, are externally caused and acute in nature. Thus, injuries are unique compared to other long-term health outcomes related to these same factors (Potter et al., 2005). Therefore, the inclusion of neighbourhood characteristics in this investigation is vital to understanding the contributing factors of injuries.

Despite an understanding that the nature of the association between injuries and neighbourhood characteristics is important to minimise injury risk, no previous study has analysed the association between neighbourhood characteristics and sport/leisure injuries (Singh et al., 2016). Most sport/leisure injury epidemiological studies have explored only immediate or internal risk factors for injury (i.e., factors within the individual's control such as equipment, training-related behaviours and rules and regulations). However, in explaining why certain populations are consistently at greater risk, it is necessary to study external factors such as neighbourhood diversity, social, economic and environmental factors (Bell & Schuurman, 2010).

The first fundamental geographic question, 'Where are the high incidence areas?' in relation to sport/leisure injuries was addressed in Chapters 5 and 6. The next geographic question is 'What geographically relevant factors may have contributed to that observed pattern?' Thus, the aim of this chapter is to investigate the association between neighbourhood characteristics and activity and activity-specific sport/leisure injury hospitalisations in Victoria.

7.2 Methods

7.2.1 Sport/leisure injury data

The sport/leisure injury data used in this study are the same as those outlined in Chapter 4. The overall and activity-specific crude annual incidence rates per 100,000 participants were calculated using 2011 participation estimates as the denominator for all Victorian LGAs.

7.2.2 Neighbourhood characteristics

The selected neighbourhood diversity, social engagement, socio-economic and education characteristics were investigated to understand the geographical variation of sport/leisure injury hospitalisation rates in Victoria. The selected neighbourhood characteristics are:

1. population born in a non-English speaking country (diversity)
2. members of a sports group (social engagement)
3. people with an income less than A\$400 per week (socio-economic)
4. people who have not completed Year 12 (education).

People born in a non-English speaking country (diversity) have been associated with higher rates of injury-cause categories such as occupational and road-related injuries (Anikeeva et al., 2010). This may be due to a limited ability to understand safety information presented only in English (Trajkovski & Loosemore, 2006). Specifically, in sport/leisure sector, it is also important that all sport/leisure participants understand safety information to minimise the risk of injury. Another neighbourhood characteristic, membership in a sports group (social engagement), is considered an indicator of sport/leisure injury. Members of sports groups may be more likely to participate in safer sports environments than those who are not members. It can be hypothesised that the members who do participate in safer sports environments (well-maintained grounds and facilities with good equipment and qualified coaches and officials) would be exposed to a reduced risk of sport/leisure injury compared to those with no access to similar resources (Finch et al., 2003). The availability and accessibility of safe sports environments may depend on the SES of the neighbourhood. A low number of hospitalisations is expected in higher socio-economic areas because of the possible availability of safe sport/leisure facilities and the financial resources of participants to use those facilities. It can be hypothesised that people with weekly income of less than

A\$400 are less likely to afford the cost of sports participation in a safe environment. Thus, they are more likely to be injured during the sport/leisure participation. Education level, as a key sociodemographic factor, may also influence sport/leisure injuries because people with higher qualifications have a greater capacity to understand safety messages and are more likely to actively encourage their children to participate in safe environments.

The selected neighbourhood characteristics data (in terms of both proportion of the population and rank) measured at LGA level were obtained from DHHS and the Victorian government (DHHS, 2015). The standardised ranks of each LGA of selected variables (i.e., for each variable, LGAs were ordered from 1–79 accordingly) were used in regression models. The rank of each variable was determined by DHHS internally using LGA-based indices data from the Census of Population and Housing (2011), conducted by the ABS and Victorian Population Health Survey (2011). The selected neighbourhood characteristics are presented in choropleth maps.

7.2.3 Modelling the neighbourhood characteristics and injury relationship

The Pearson correlations were calculated between each dependent variable (injury hospitalisation rates for sport/leisure, Australian Football, soccer, basketball and cricket) and the ranks of selected neighbourhood characteristics to determine the magnitude and direction of their associations. These calculations were conducted using SPSS software Version 21 (Corp, 2012). The neighbourhood characteristics that exhibited significant association (Pearson correlations $p < 0.05$) with the dependent variable were included in the regression models. OLS and GWR models were used to explore the relationship between injury rates and selected explanatory variables. The OLS and GWR models were computed using the spatial statistical toolbox of ArcGIS 10.5 (ESRI, 2011).

The OLS was used to determine the combination of explanatory variables to be included in the final regression analysis. The OLS was also used to test for redundancy among predictors. The OLS model is given as:

$$y_i = \beta_o + \sum_{j=1}^p X_{ij}\beta_j + \epsilon_i$$

Where:

β_o = intercept coefficient

β_j = slope coefficient for the J^{th} independent variable X_j

ε_i = random error term with $N(0, \sigma^2 I)$

I = $n \times n$ identity matrix

In matrix notation, the model can be represented by

$$Y = X\beta + \varepsilon$$

The statistical significance (F-value and corresponding p-value) of the model was tested using analysis of variance (ANOVA). Any linear intercorrelation among model explanatory variables is referred as multicollinearity; high multicollinearity leads to statistical measures that are unreliable and unpredictable. The variance inflation factor (VIF) value was used to test for multicollinearity. A VIF value greater than 10 confirms the existence of multicollinearity. If any explanatory variable returned a VIF value greater than 10, the model was recalibrated by removing those variables. The residuals of the final models were tested for spatial autocorrelation using the global Moran's I tool.

The OLS is a global model because it assumes the relationship is constant across the study region. Injury rates are spatially dependent as identified in Chapter 4; thus, using OLS to measure the relationship between injury rates and explanatory variables may be inappropriate. The OLS does not consider the spatial dependency exhibited in explanatory and dependent variables. For this reason, a local regression technique, GWR, was also used, which is based on three principles: (i) spatial data are not often stationary, (ii) relationships between variables are greatly influenced by spatial structure, and (iii) localised relationship between variables may vary across space (Hanham & Spiker, 2005). The basic GWR model (Fotheringham, Charlton & Brunsdon, 1998) is given as:

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i)x_{ik} + \varepsilon_i$$

Where:

(u_i, v_i) = geographic coordinates of i^{th} point

$\beta_k(u_i, v_i)$ = realisation of the continuous function at point i

ε = random error.

The residuals of the GWR models were tested for spatial autocorrelation using Moran's I . The local R^2 values from each model were presented in the form of choropleth maps to visualise the strength of relationship between dependent and explanatory variables.

7.3 Results

The maps depicting the ranks of the selected neighbourhood characteristics by LGA is presented in Figure 7.1. The significant positive spatial autocorrelation as indicated by the z-score (> 2.58) was observed in the distribution of the neighbourhood characteristics (see Table 7.1).

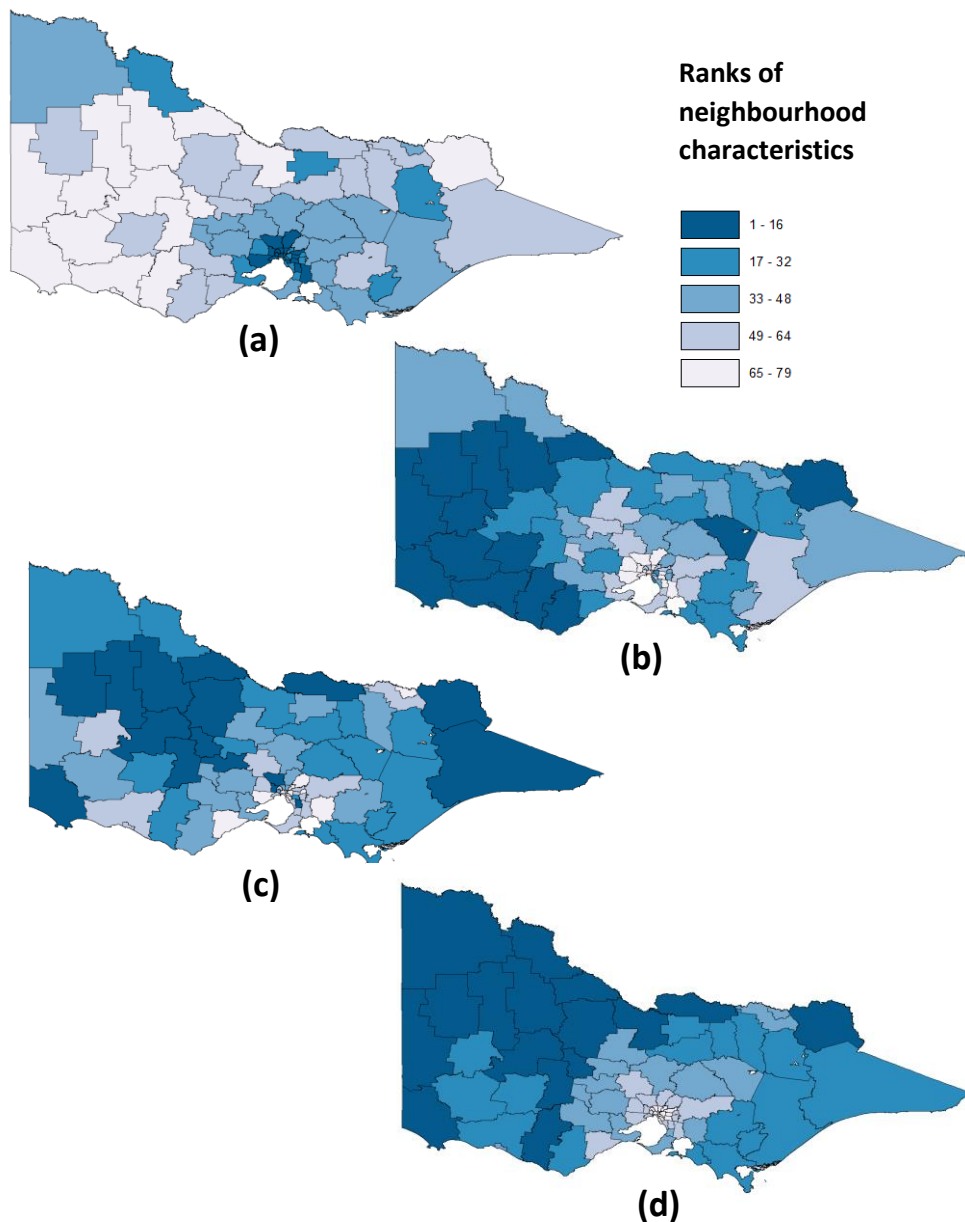


Figure 7.1: Maps depicting the ranks of (a) percentage of people born in non-English speaking country (rank), (b) percentage of people who are members of the sports group (rank), (c) percentage of people with income less than A\$400 per week (rank), and (d) percentage of people who did not complete Year 12 (rank)

Table 7.1: Spatial autocorrelation test of selected neighbourhood characteristics

Neighbourhood Characteristics	Moran's <i>I</i> Score	z-score
Population born in a non-English speaking country (rank) (diversity)	0.769	16.285
Members of the sport group (rank) (social engagement)	0.586	12.465
People with income less than A\$400 per week (rank) (economic)	0.417	8.938
People who did not complete Year 12 (rank) (education)	0.835	17.659

Table 7.2: Pearson correlation between the dependent variable and selected neighbourhood characteristics as explanatory variables

Explanatory Dependent	Population Born in a Non-English Speaking Country (Rank)	Members of the Sport Group (Rank)	People with Income Less Than A\$400 per Week (Rank)	People Who Did not Complete Year 12 (Rank)
Sport/leisure injury hospitalisation rates	0.591**	-0.566**	0.027	-0.280*
Injury hospitalisation rates	0.749**	-0.718**	-0.306**	-0.645**
Soccer injury hospitalisation rates	-0.781**	0.663**	0.352**	0.752**
Basketball injury hospitalisation rates	-0.191	0.108	0.393**	0.341**
Cricket injury hospitalisation rates	0.340**	-0.291**	-0.011	-0.183

** Correlation is significant at 0.01 level; * correlation is significant at 0.05 level.

The Pearson correlations between the overall and activity-specific injury hospitalisation rates and neighbourhood characteristics are presented in Table 7.2. The overall sport/leisure injury hospitalisation rates were significantly associated with selected social engagement, diversity and education neighbourhood characteristics, but not significantly associated with economic characteristics. Both Australian Football and soccer injury hospitalisation rates were significantly associated with all selected neighbourhood characteristics. Basketball injury hospitalisation rates were not significantly associated with social engagement and diversity

characteristics, while cricket injury hospitalisation rates were not significantly associated with economic and education characteristics. The neighbourhood characteristics that were not significantly associated with respective dependent variables based on these correlations were not included in overall and activity-specific regression models.

7.3.1 OLS regression model

The results of the OLS models are presented in Table 7.3. The model returned VIF values in all regression models lower than the set redundancy threshold of 10, suggesting no redundancy among the selected neighbourhood characteristics in all regression models. The OLS global models showed that the selected explanatory variables for each dependent variable explained from lowest of 9.3 per cent of cricket injury hospitalisations to highest of 67.8 per cent of soccer injury hospitalisations.

The standardised residuals of the OLS models are presented in Figure 7.2, in which the blue and red represents over and under-predicted areas respectively. Visual inspection of the maps shows potential clustering of over and under-predicted areas. The residuals were statistically tested using the global Moran's *I* method. As shown in Table 7.2, the residuals of OLS models exhibited statistically significant spatial autocorrelation (z -score > 1.65), indicating that the OLS model does not fit the data properly. Thus, a model that considers spatial dependency is needed.

Table 7.3: Result of OLS regression models and spatial autocorrelation test using Moran's *I* of the standardised residuals of OLS regression models

Models	Explanatory Variables	R ² Adj	AICc	Standardised Residuals	
				Moran's Index	z-score
Overall	Population born in non-English speaking country	0.445	921.5	0.143	3.374
sport/leisure injury	Members of the sports group				
hospitalisations	People who did not complete Year 12				
Australian Football injury hospitalisations	Population born in non-English speaking country	0.576	1281.7	0.168	3.847
	Members of the sports group				
	People with income of less than A\$400 per week				
	People who did not complete Year 12				
Soccer injury hospitalisations	Population born in non-English speaking country	0.678	983.4	0.172	3.862
	Members of the sports group				
	People with income less than A\$400 per week				
	People who did not complete Year 12				
Basketball injury hospitalisations	People with income less than \$400 per week	0.138	957.1	0.309	6.783
	People who did not complete year 12				
Cricket injury hospitalisations	Population born in non-English speaking country	0.093	867.5	0.137	3.245
	Members of the sports group				

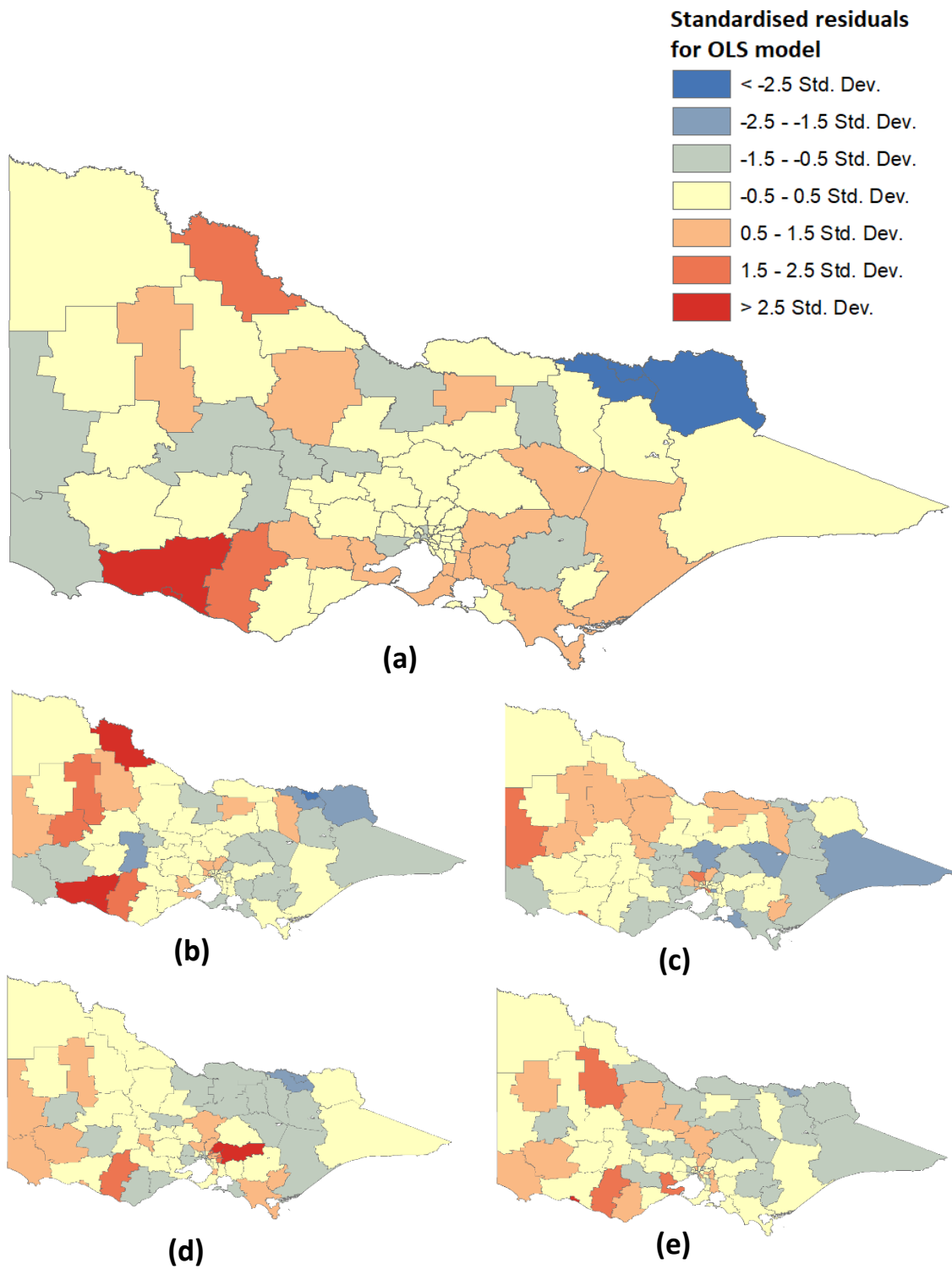


Figure 7.2: Standardised residuals of OLS regression models (a) overall injury hospitalisations, (b) Australian Football injury hospitalisations, (c) soccer injury hospitalisations, (d) basketball injury hospitalisations and (e) cricket injury hospitalisations

7.3.2 GWR regression model

The GWR model results are presented in Table 7.4. They showed a significant model improvement compared to the global OLS models. Comparison of the respective model's AIC values showed a decrease in Akaike's Information Criterion (AICc) values ranged from 3.98 in basketball to 46.39 in overall injuries. The decrease in AICc values indicates that the GWR model fitness better explains the spatially dependent overall and activity-specific injury rates. This is confirmed by the adjusted R^2 being increased in the GWR models compared to OLS models. The GWR model improved the explaining power of the OLS model by 6.4, 7.1, 19.8, 19.8 and 27.6 per cent for soccer, basketball, Australian Football, cricket and overall injury hospitalisations respectively.

The standardised residuals of the GWR models are presented in Figure 7.3. As shown in Table 7.4, the spatial autocorrelation test of residuals of the GWR models for overall, basketball and cricket injury hospitalisations now indicate no spatial dependency (z-score < 1.65). This means that these models are properly specified. In the case of GWR models for Australian Football and soccer injury hospitalisations, the z-scores are reduced, indicating the GWR models are a better fit than OLS models.

Figure 7.4 displays the local strength of the relationship (local R^2) between the dependent and selected explanatory variables. The dark and light blue indicates the strong and weak relationships respectively. As observed in Figure 7.4, the strength of the relationship varied across the study region. Importantly, the spatial pattern of relationship across the injury groupings were different. For example, the relationship between overall sport/leisure injury hospitalisation rates and selected explanatory variables (population born in a non-English speaking country, members of the sport group and people who did not complete Year 12) was strong in south-west Victorian LGAs. This means the selected neighbourhood characteristics explained the higher proportion of injuries incurred in those areas. In contrast, the relationship between Australian Football injury hospitalisations and selected variables was observed to be strong in LGAs of metropolitan and inner regional western Victoria.

Table 7.4: Result of GWR regression models and spatial autocorrelation test using Moran's *I* of the standardised residuals of GWR regression models

Models	Explanatory Variables	R ² Adj	AICc	Standardised Residuals	
				Moran's Index	z- score
Overall	Population born in non-English speaking sport/leisure country	0.721	875.1	0.013	1.507
injury	Members of the sports group				
hospitalisations	People who did not complete Year 12				
Australian	Population born in non-English speaking country	0.774	1240.4	-0.008	0.297
Football injury	Members of the sports group				
hospitalisations	People with income less than A\$400 per week				
	People who did not complete Year 12				
Soccer injury	Population born in non-English speaking country	0.741	972.4	-0.051	-2.183
hospitalisations	Members of the sports group				
	People with income less than A\$400 per week				
	People who did not complete Year 12				
Basketball	People with income less than A\$400 per week	0.209	953.1	-0.006	0.376
injury	People who did not complete Year 12				
hospitalisations	People who did not complete Year 12				
Cricket injury	Population born in non-English speaking country	0.291	854.3	-0.029	0.914
hospitalisations	Members of the sports group				

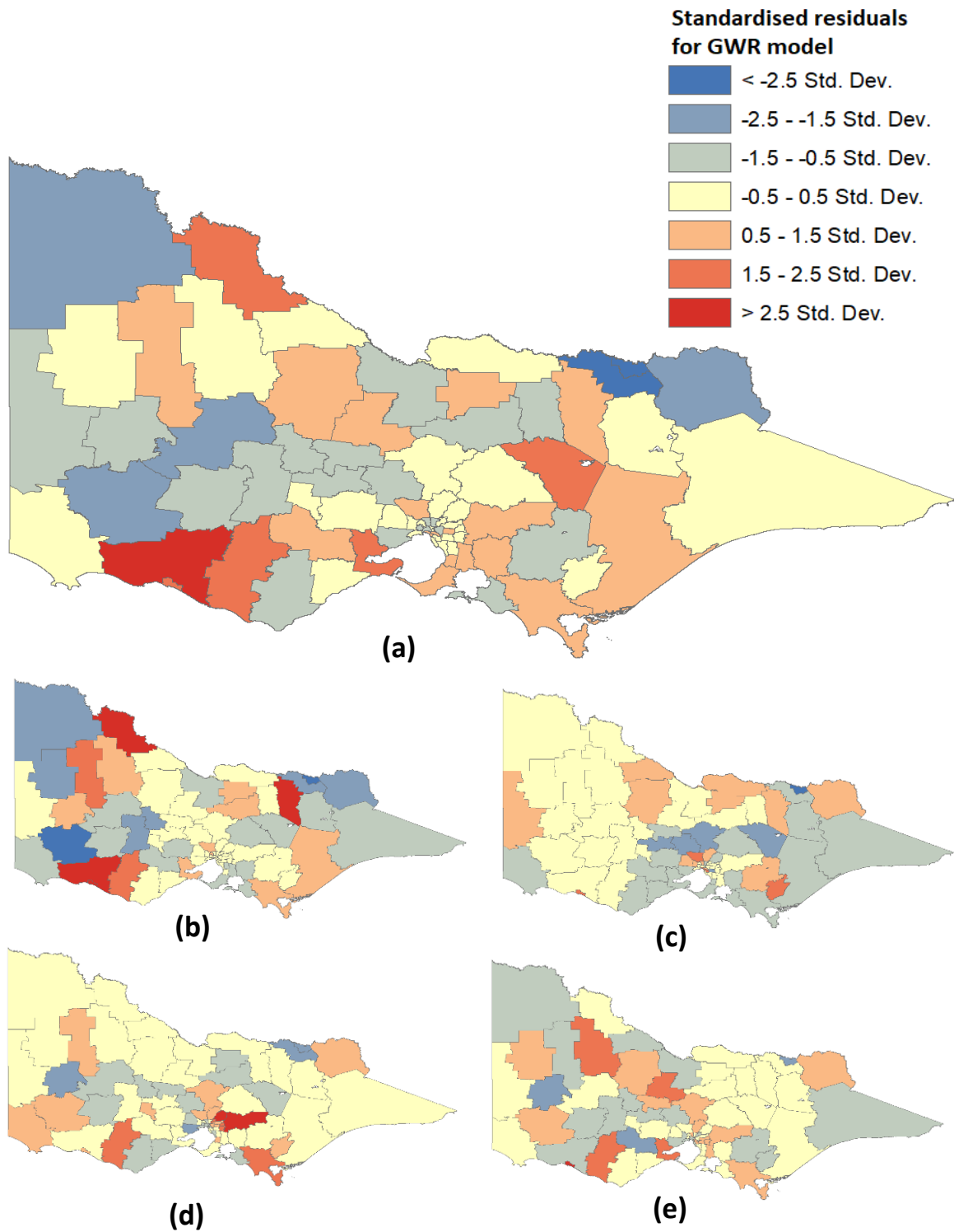


Figure 7.3: Standardised residuals of GWR regression models (a) overall injury hospitalisations, (b) Australian Football injury hospitalisations, (c) soccer injury hospitalisations, (d) basketball injury hospitalisations and (e) cricket injury hospitalisations

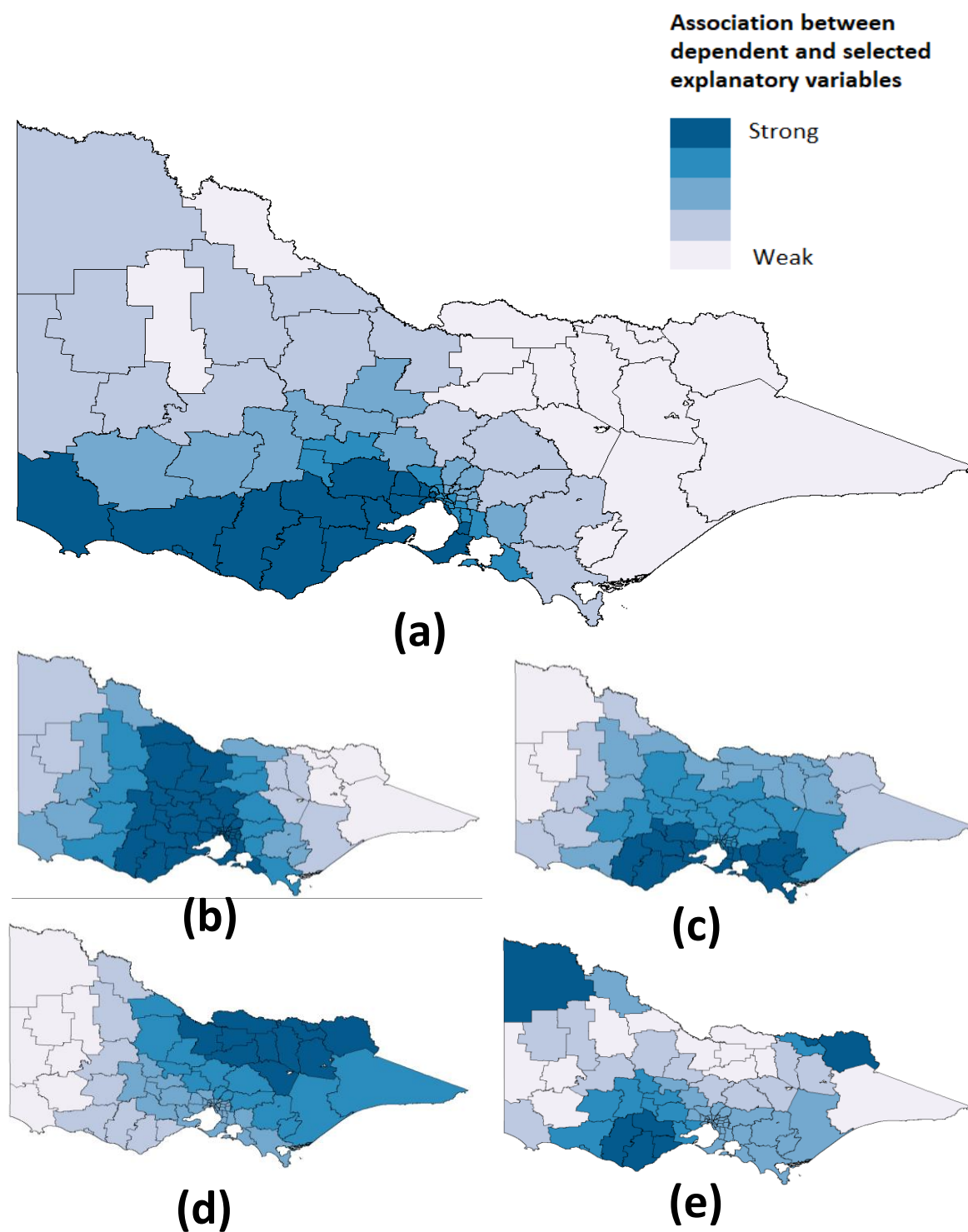


Figure 7.4: Strength of association between (a) overall injury hospitalisations, (b) Australian Football injury hospitalisations, (c) soccer injury hospitalisations, (d) basketball injury hospitalisations and (e) cricket injury hospitalisations and selected explanatory variables

7.4 Conclusions

This chapter investigated the relationship between overall and selected sport-specific injury rates in relation to selected diversity, social engagement, education and economic variables. The Pearson correlations suggested that perhaps not all selected explanatory variables were significantly associated with overall and some activity-specific injury hospitalisation rates. Further, the magnitude and direction of the association was discovered to be different in some cases between dependent and explanatory variables. For example, neighbourhoods (i.e., LGAs) with high ranks of income (people with weekly incomes less than A\$400) and education (people who did not complete Year 12) characteristics were associated with higher Australian Football injury hospitalisation rates. However, an inverse relationship was observed between income and education characteristics and soccer injury hospitalisations.

The OLS and GWR models using selected explanatory variables were generally statistically significant. However, the findings suggested that the GWR model performed better than did the OLS models in comparing R^2 and $AICc$ values. This is likely due to the spatial autocorrelation exhibited within the overall and activity-specific injury hospitalisation rates (Singh et al., 2016). Previous studies have applied the GWR model to model traffic crashes and drowning and demonstrated that the GWR performance is better than global models such as OLS (Dai et al., 2013; Zhang, Bigham, Ragland & Chen, 2015). The improved result of the GWR model indicates that the nature of association varies in space between explanatory variables and dependent variables. Importantly, the spatial pattern of association between dependent and explanatory variables appears to be differently associated with each sport differently across locations. This chapter provides insights into the importance of external sociodemographic factors for better understanding sport/leisure injuries by demonstrating significant associations between dependent and selected explanatory variables in geographic scale. As many of these factors are not modifiable, it is likely that the targeting of sport/leisure injury prevention strategies and programs will need to be customised based on their associated explanatory variables with specific sport in different geographic locations.

Chapter 8: Victorian Atlas of Sport and Leisure Injuries (VASLI): A Web-based GIS Tool for Exploratory Analysis of Sport and Leisure Injury Data in Victoria

8.1 Introduction

It is crucial for decision-makers to have timely access to health-related information that can be easily understood and interpreted to facilitate evidence-based decision-making in public health (Brownson et al., 2009; Jardine et al., 2014). With the increasing availability of high-quality health and health-related datasets with locational information, it is possible to present data in the form of maps. Mapping of health data dates back to 1854, when Dr John Snow mapped cholera cases to investigate a cholera outbreak in London (Snow, 1855). Visualising health data in the form of maps is a powerful tool for investigating trends and disseminating information (Martinez et al., 2016). However, the use of mapping is often limited to static maps reported in routinely produced government reports and research papers. Thus, the spatially referenced health information available to decision-makers and key stakeholders has generally been limited (Joyce, 2009).

The process of sharing information has been revolutionised in the last decade due to advancements in technology, especially web-based technologies. Now, the most common way to share information is through the internet. With the recent advancement in web-mapping technologies, it is now possible to provide customised information with detailed spatial resolution in a timely manner to health professionals and decision-makers (Jardine et al., 2014). Recently, there has been an increased interest in the development of web-based visualisation tools to provide information on public health issues such as cancer, malaria and dengue (Luan & Law, 2014; Yi et al., 2008). These tools not only enable visualisation of raw data, they also provide a powerful tool to investigate trends and patterns through data visualisation. The mapping component of these online tools is also referred to as web-GIS. Web-GIS is a useful tool to empower decision-making, plan effective strategies and inform and educate people at all levels (Boulos, 2004). Web-GIS is a platform that is more efficient for disseminating georeferenced data, thereby enabling efficient data use and evidence-based public health interventions (Jardine et al., 2014).

The spatial epidemiological investigation of sport/leisure injuries was presented in previous chapters of this thesis. The findings suggest a notable geographic variation in sport/leisure injury hospitalisations in Victoria. Hence, they indicate the importance of geographical analysis in the sports injury context. In addition, the findings provide a strong evidence base for the targeting of strategic planning and development of sports injury prevention programs. However, these findings may not be accessible or available to all stakeholders or may not be in an appropriate form. For this reason, a web-based GIS, the Victorian Atlas of Sport and Leisure Injuries (VASLI), was developed to allow users access to the tool from anywhere to perform exploratory analysis based on their requirements. This chapter will focus on the development of the web-GIS tool for exploratory analysis of sport/leisure injury hospitalisations data in Victoria.

8.2 Design Overview

8.2.1 System design

The VASLI was developed using the open-source framework (Moncrieff, West, Cosford, Mullan & Jardine, 2014) depicted in Figure 8.1. The major components of web-GIS include: data storage, a server to process requests, spatial analysis packages and a client interface. The database management system (DBMS) contains a database tier, where all data and associated metadata are stored. The DBMS is responsible for providing data security and integrity and managing simultaneous requests from the web server. For data storage, a PostGIS (spatial extension of PostgreSQL) database was selected because of the requirement to store complex geometry objects (LGA boundaries of Victoria). The PostGIS is one of the most popular open-source spatial database. Additionally, a recommended DBMS for server-side technologies was used in this framework.

The model-view-template (MVT) software architecture was used to design the server module. The MVT approach is suitable for implementing representational state transfer (REST) interfaces. A python geographic web framework, GeoDjango, was used for the development of the server (Django Software Foundation, n.d). This supports server access to spatial data within a PostGIS database when responding to a REST query string. The python package PySAL used in this framework provides classification and spatial analysis capabilities (Rey & Anselin, 2010). In this architecture, the communication of information between the client and server is performed using a data interchange format (e.g., JavaScript object notation

[JSON]). The leaflet java script library is used to develop a client interface with interactive maps.

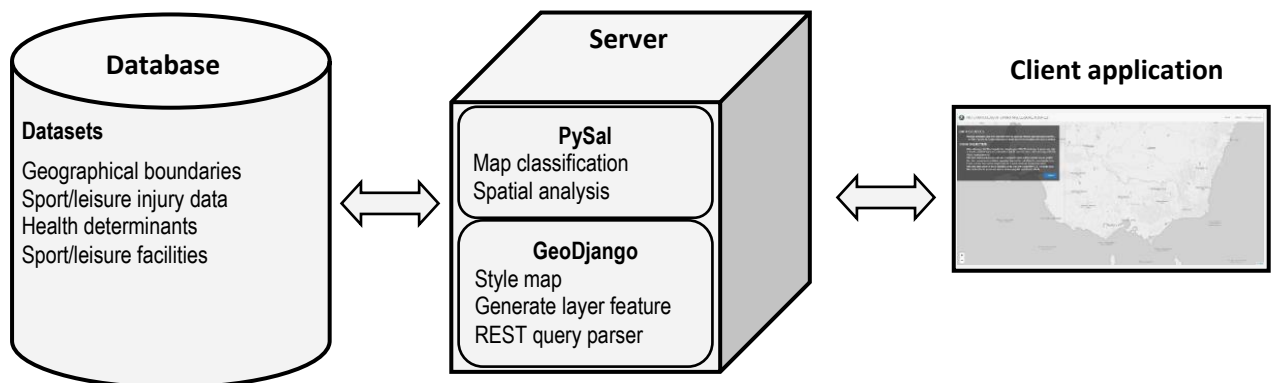


Figure 8.1: Open-source framework used to develop VASLI

8.2.2 Datasets

The following datasets used in the previous chapters of this thesis were imported into the PostGIS database:

- sport/leisure injury hospitalisation data
- geographical boundaries
- accessibility/remoteness index
- SES categories
- neighbourhood characteristics
- demographic data.

8.3 Results

Figure 8.2 shows the client application of VASLI: the homepage, information about the sport/leisure injury data source, case selection criteria and a button to explore available datasets.

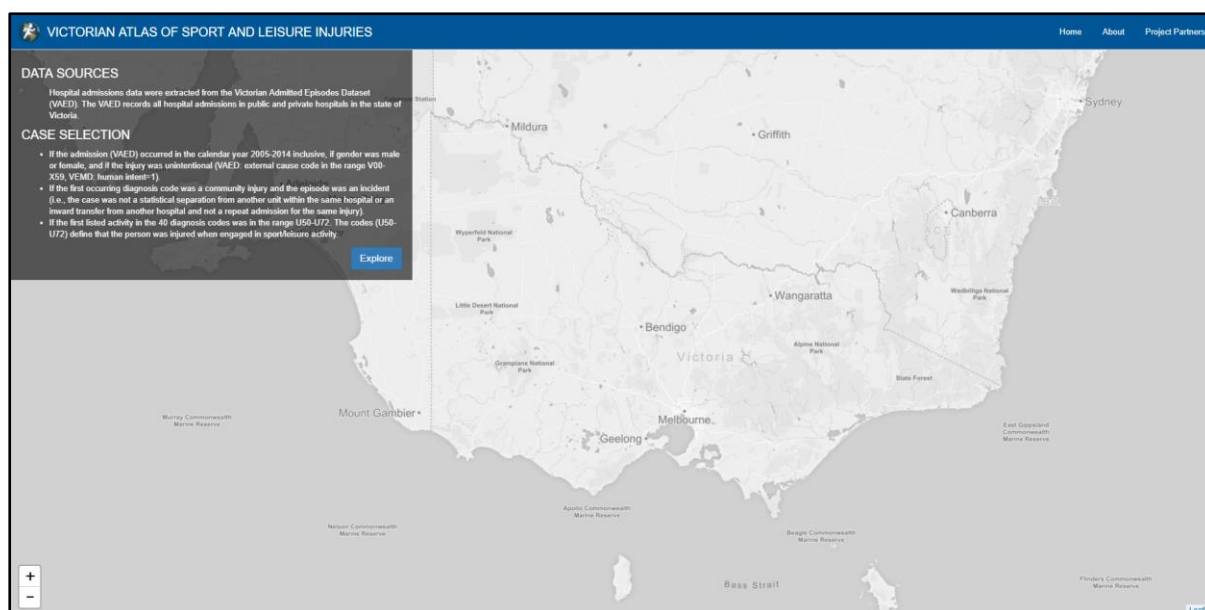


Figure 8.2: Homepage of VASLI

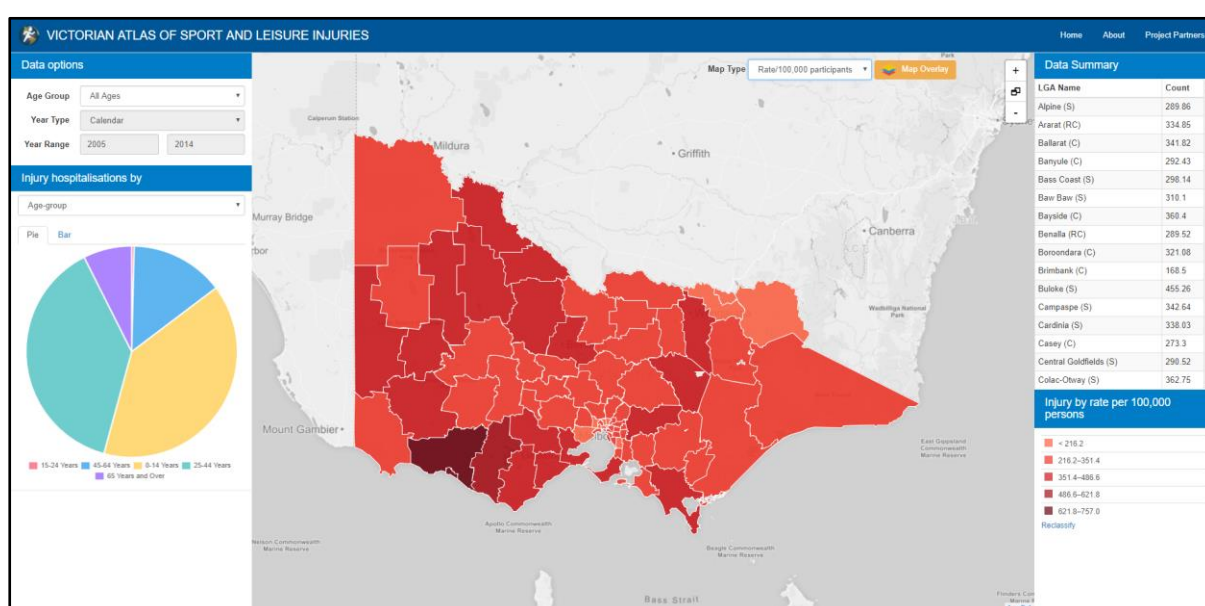


Figure 8.3: Application page to explore sport/leisure injuries

When a user clicks 'explore', an application page is displayed (see Figure 8.3). The application page includes map area, data options, map overlays, chart variables and chart window. The default map (i.e., the first map displayed when a user clicks 'explore') represents sport/leisure injury hospitalisation rates (all ages) per 100,000 participants/year by Victorian LGAs, classified into five classes using the equal interval method. When 'all ages' is selected, a user can also explore the distribution (proportions of all cases) of Victorian sport/leisure injuries by different variables such as age groups, sex, place of occurrence, nature of injury, body region categories and bed days categories. To explore the distribution

by the abovementioned variables, users can select a variable from a dropdown menu and a chart is displayed.

Injury distribution by these variables is not available for the other age groups (e.g., people aged 0–14 and 15–24 years) due to a limitation in data. Therefore, in the current version, when a user selects ‘other than all ages’ in year range, a chart area is not visible (see Figure 8.4).

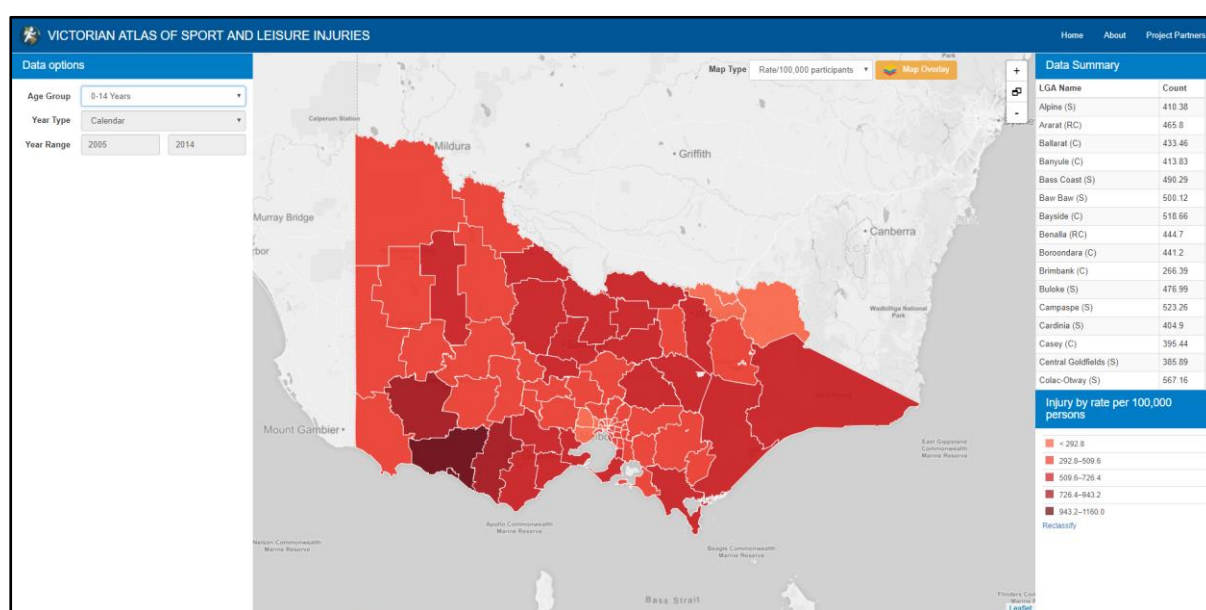


Figure 8.4: Map showing the sport/leisure injury hospitalisation rate per 100,000 participants for people aged 0–14 years in Victoria, 2005–2014 inclusive

To reclassify the map, a user can click ‘reclassify’ and resulting options will appear (see Figure 8.5). The user can select from a range of methods, such as equal interval, quantile and natural Jenks, depending on the requirements. The map classification techniques were incorporated from the *PySAL esda.mapclassify* library. During the classification, users can also provide other parameters including number of breaks and colour scheme for a better display of maps and classes.

Another feature of the VASLI is the analysis of injury rates by remoteness, SES categories and other selected neighbourhood characteristics (see Chapter 7). When a user selects a map overlay from the dropdown menu, a map showing different categories is displayed in the map

area and the resulting chart shows the rates within each category displayed in the chart area (see Figure 8.6).

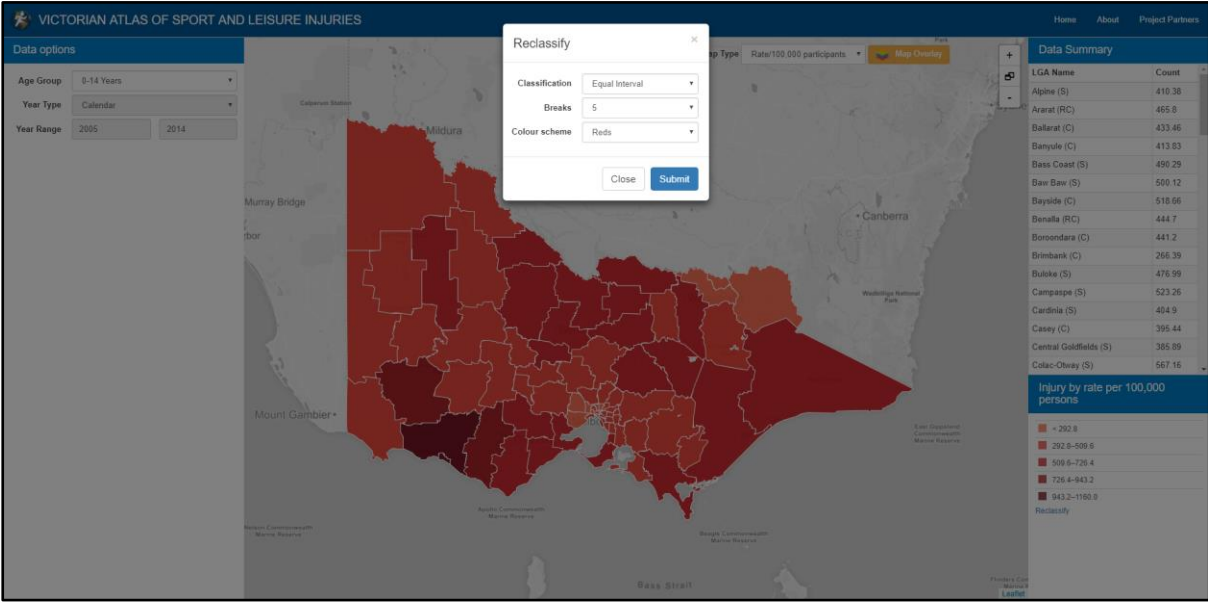


Figure 8.5: Reclassify option parameters to reclassify a map

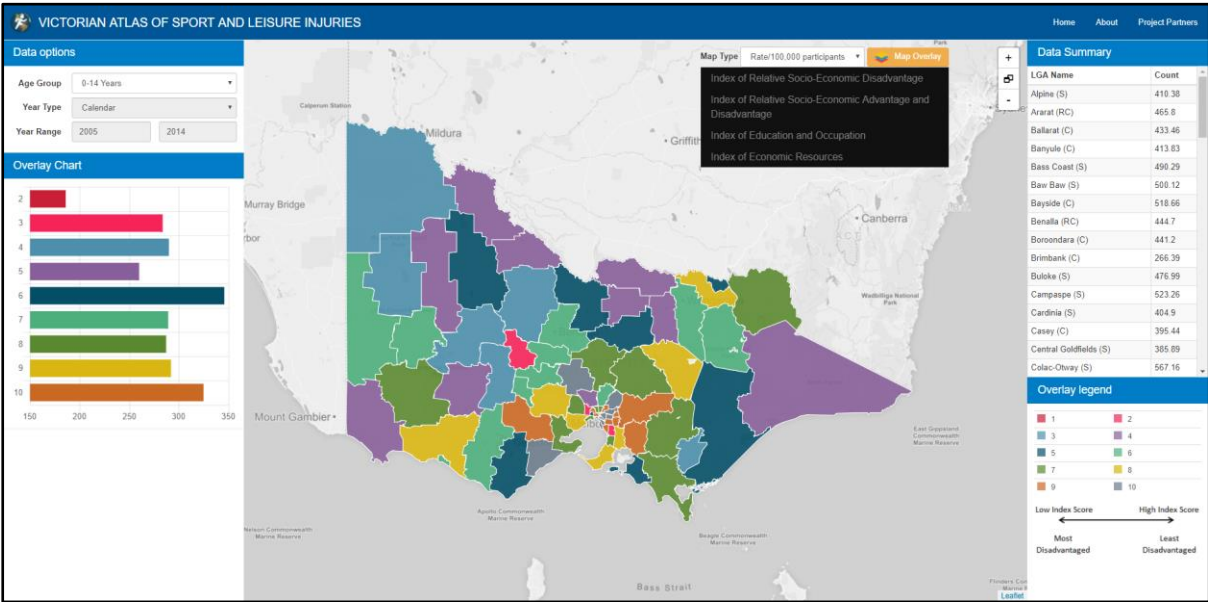


Figure 8.6: Map showing the SEIFA categories and chart showing injury hospitalisation rates for all ages as selected in data options in each socioeconomic categories

The VASLI is currently accessed from this link <http://vicinjuryatlas.com:8000/victoria/>.

8.4 Conclusions

A web-based GIS tool was developed for the exploratory analysis of sport/leisure injury hospitalisation data of Victoria. Technological advances and the availability of a wide range of open-source technologies have enabled the development of a cost-effective mapping and visualisation tool for public health. A number of web-based visualisation tools were developed globally in recent decades to interact in real-time with the databases and generate customized reports and maps (Jardine et al., 2014; Luan & Law, 2014; Thew et al., 2011; Highfield, Arthasarnprasit, Ottenweller & Dasprez, 2011). Published evaluations and user testing of web-based visualisation tools has revealed important insight that the use of spatial information by key stakeholders has increased with the web-based visualisation tool (Jardine et al., 2014).

VASLI enables users to visualise sport/leisure injury hospitalisation data and other related data without the need for any additional software or prior knowledge of GIS. The common reports that can be generated using the VASLI are choropleth maps of incidence rates by LGA for different age groups and graphs showing injury distribution in Victoria by categories of demographic and injury characteristics. An important feature of this tool is a reclassification functionality that is used to reclassify (creating a number of classes based on different methods) the injury data to better understand the geospatial pattern of injuries. The implementation of reclassify functionality within this tools also indicates that that other geospatial methods such as hot spot analysis and spatial regression methods can be implemented in future projects.

Chapter 9: Discussion and Conclusion

9.1 Overview of the Novel Approach

The overall aim of this thesis was to conduct the first detailed spatial epidemiological investigation of sport/leisure injuries in Victoria. The focus was on hospital-treated injuries given their public health burden and the ready access to existing data sources.

A review conducted as part of this thesis revealed a limited application of spatial epidemiological approaches to sport/leisure injury research. This is despite recognition that the spatial epidemiological approaches are commonly applied to investigate road traffic injuries, falls, drowning and burns (Aguero-Valverde & Jovanis, 2006; Lai, Low, Wong, Wong & Chan, 2009; Poulos et al., 2009; Singh et al., 2016). The spatial epidemiological themes used in the reviewed studies were (i) mapping, (ii) clustering or cluster detection and (iii) ecological analysis. The identified themes mainly focused on Steps 1 (surveillance) and 2 (aetiology and mechanisms) of the Sequence of prevention model from the geographical perspective (van Mechelen, Hlobil & Kemper, 1992). There is clear potential for these steps to be applied in sport/leisure injury epidemiological research.

It is well established that the use of geospatial methods in injury research provides important insight into injury distribution and causation that support prioritising and developing injury prevention strategies and policies (Dai et al., 2013; Goltsman et al., 2014; Lawrence et al., 2015; Poulos et al., 2012). With this evidence, and the fact that the use of geospatial methods is very limited in the sport/leisure injury context, this thesis has identified geospatial methods as a novel approach for better understanding sport/leisure injuries to support the development of effective injury prevention programs (Singh et al., 2015).

Many findings reported in this thesis will not be readily available or accessible to key stakeholders. The traditional approaches to reporting research findings can be enhanced if new approaches are supported to make research data available in user friendly and intuitive ways to key stakeholders (Jardine et al., 2014). Therefore, this research has also used web-based GIS technologies to develop a new tool to help disseminate sport/leisure injury spatial epidemiological and relevant information to a wide audience. The VASLI was developed using open-source geospatial and web technologies to enable exploratory analysis of sport/leisure injury hospitalisation data that can be used by public health professionals and

policymakers to facilitate evidence-based decision-making. The VASLI is the first tool to present sport/leisure epidemiological information in an online platform in Australia.

9.2 Summary of Key Findings

Place can be associated with injury aetiology and subsequent outcomes (Bell & Schuurman, 2010; Edelman, 2007). There is compelling evidence that the influence of geography on injury occurrence can be investigated with the application of spatial epidemiological research (Dai et al., 2013; Goltsman et al., 2014; Poulos et al., 2009). Therefore, the potential application of the spatial epidemiological approach to investigate the place effect on sport/leisure injury occurrences was discussed in Chapter 2. Particularly, three main themes of spatial epidemiological approaches (mapping, clustering and cluster detection, and ecological analysis) were discussed and identified for their potential application in sport/leisure injury epidemiological research.

Since geospatial methods are used for the spatial epidemiological investigation, a review of such methods was conducted in Chapter 3. This review explored specific methods used under each spatial epidemiological theme. It focused on the use of the spatial epidemiological approach in sport/leisure injury research. It demonstrated that there is a lack of spatial epidemiological investigation in sport/leisure injury research, despite an increased interest in the application of spatial epidemiological approach in broader unintentional injury epidemiological research. The findings suggested that the most common spatial epidemiological analysis theme was mapping followed by clustering and ecological analysis. This indicates that the use of detailed spatial epidemiological investigation in broader unintentional injury epidemiological research is still limited.

The most common injury-cause categories that used one or more spatial epidemiological themes were road traffic injuries, falls, drowning and burns. A range of geospatial methods was identified within each theme, indicating that the selection method depends on several aspects, such as spatial resolution, spatial coverage and intensity, and availability of methods in common GIS software (Fritz et al., 2013; Singh et al., 2016; Waller & Gotway, 2004). A choropleth map is the most commonly presented tool in the reviewed papers. It is used to display statistical measures such as incidence rates, relative risk and standardised morbidity/mortality ratios. For point data, a dot map or density map is more commonly presented. The smoothing techniques, EB and BYM, were used to improve the accuracy of

incidence rate estimates in small areas or to address small number problems in geographical analysis.

The most commonly used cluster detection method in published injury studies for point data was KDE. For areal data, it was local indicators of spatial association. Additionally, this review revealed a difference in the choice of methods used in unintentional injuries compared to broader public health research. Reasons for the differences in choice of methods, whether they are, for example, lack of familiarity with geospatial methods or requirements with the type of data used, are unknown. Determining why different methods are used and the best choices of methods for unintentional injuries was beyond the scope of the review presented in chapter 3 (as the aim was to apply methods to sport/leisure injury, not to evaluate methods) but investigation of this would be of interest. The local spatial regression technique, GWR, was most commonly used to investigate relationships between dependent variables and geographically linked neighbourhood characteristics. The fundamental merit of GWR is its ability to consider spatial variation that may present in the data and display the geographically varying relationship between dependent and explanatory variables (Dai et al., 2013; Lawson, Schuurman, Amram & Nathens, 2015; Zhang et al., 2015). The conclusions from this review were used to identify and select appropriate methods for each theme to be used in the spatial epidemiological investigation of sport/leisure injuries in Victoria in subsequent thesis chapters.

Sport/leisure injury hospitalisation data were identified as the most appropriate dataset available for spatial epidemiological investigation because this data has been consistently recorded over large geographical areas (i.e., Victoria) using standard coding systems for many years. Additionally, the injury hospitalisation dataset contains the LGA and postcode of the injured person as a geographical reference, which enables area-level spatial epidemiological investigation. Most commonly in epidemiological studies, sport/leisure injuries have been analysed in regard to activity, place settings, nature of the injury, body region injured and length of stay in hospital (Cassell et al., 2012; Flood & Harrison, 2009; Kreisfeld et al., 2014). Therefore, the sport/leisure injury hospitalisation data aggregated by these variables for each LGA and postcode of Victoria were obtained. The participation-adjusted incidence rate was used as a summary measure in this PhD research for all analyses.

In line with previous studies (Conn et al., 2003; Finch et al., 2011; Lam, 2005; Mitchell & Hayen, 2006), this study has confirmed that males are more commonly injured during

sport/leisure participation than females across all age groups. This may be because of the very high participation of males in the most common sport/leisure activities leading to hospitalisations, such as Australian Football, soccer, football, basketball and cricket (ASC, 2010). Another possible explanation could be that the risk-taking behaviour of males is comparatively higher than it is in females, thereby predisposing them to more injuries (Turner & McClure, 2003). Many studies have shown the higher incidence of sport/leisure injuries to be among people aged 5–24 years (Belechri, Petridou, Kedikoglou & Trichopoulos, 2001; Cassell et al., 2003; Conn et al., 2003; Finch et al., 2011); this was supported by the findings of this thesis. This reflects the higher participation of this age group in organised or unorganised school sports that have greater injury risk and the lack of technical knowledge regarding sports and safe participation at this age (Belechri et al., 2001). Therefore, preventive measures could include involving children in sporting activities at an appropriate age or providing better protection for them in years when sports become more intense (e.g., transition to greater competition and tackling) (Belechri et al., 2001).

Most injuries occurred in sports and athletics areas where mostly sport/leisure activities are undertaken such as sporting grounds, halls and swimming centres. Safe sports and athletics facilities with trained professionals could help to prevent injuries in these areas (Conn et al., 2003). The data in this thesis show that more than half the hospitalisations were for treatment of fractures. This is also the most common type of sport/leisure activity injury presented in EDs (Finch et al., 1998). In Australia, fractures have been previously reported as the most common injury in sports such as skateboarding, roller skating/blading, soccer, Australian Football and rugby (Finch et al., 1998). Sprain and strain were the second most common type of injury for hospitalisations, and are also the most common type in GP presentations (Cassell et al., 2003; Mummery et al., 2002). Other common types of injury leading to hospitalisation were open wound and injury to muscle or tendon.

For the data presented in this thesis, the ‘knee and lower leg’ was the most commonly injured body part category, followed by the ‘elbow and forearm’, ‘head’, ‘wrist and hand’ and ‘shoulder and upper arm’ categories. The body parts within the upper extremities combined were more commonly injured than the lower extremities were. Serious injuries were strongly associated with injuries to head and spine (Gabbe et al., 2005). Nearly two-thirds of the hospitalisations were for fewer than two days, with the pattern of decreasing hospitalisation rates with increasing number of bed days. This is because most hospitalisations were

fractures and ‘sprains and strains’ that require hospital stays shorter than two days. These injuries are subsequently managed externally by GPs and other non-hospital health services.

The sport/leisure injury hospitalisation data were examined by selected categories of demographic and injury characteristics across the socio-economic and remoteness categories of Victoria (see Chapter 5). In the selected categories, there was mostly an increase in hospitalisation rates with a significant difference as remoteness increases. These findings are consistent with those reported by studies conducted in NSW (Finch & Boufous, 2009; Lam, 2005). One possible explanation for these consistent findings could be the limited availability of safe sport/leisure facilities with trained professionals in regional areas compared to metropolitan areas (Finch & Boufous, 2009; Orchard, 2002; Swan et al., 2009). Further, due to the limited availability of non-hospital healthcare facilities in regional areas, people may be more likely to be hospitalised as a result of injury than they would in metropolitan areas with a larger range of health services.

Across socio-economic categories, there was variation in the rates across selected categories. Variation in overall sport/leisure injury hospitalisation rates without any significant pattern was observed across socio-economic regions as reported in previous studies (Finch & Boufous, 2009; Lam, 2005). The observed overall sport/leisure injury hospitalisation rates were higher in regions where many people have higher incomes and are involved in skilled occupations. It is important to understand the reason for this trend. It might be expected that higher income presents opportunities for safer sport/leisure participation or better access to medical facilities other than the hospital settings. However, this was not the case with the data because the higher rates were observed in the area with high SES. Therefore, the observed pattern could be the result of variation in neighbourhood characteristics across the region such as population diversity, economic and education factors. Further exploration is required to support this hypothesis.

Although the term ‘data visualisation’ is not new in public health or injury research, the increasing availability of complex, large and geocoded datasets demands new methods to present datasets in a visual form that can be easily understood by public health professionals, policymakers and the public (Martinez et al., 2016). Data presented in visual forms are considered to be more effective to communicate hidden stories such as patterns and trends to a broad audience (Few, 2013). Of the many ways to represent data in visual form, a map is commonly used to visualise georeferenced data in public health and describe the geospatial

trend and pattern in a geographical context. However, this technique is not commonly used in sport/leisure injury research (Singh et al., 2015). Therefore, this thesis is a significant advancement on previous studies (Finch & Boufous, 2009; Lam, 2005; Lower, 1996) in its application of geospatial methods to analyse sport/leisure injuries in a geographical context using the LGA as the spatial unit for analysis and presenting the results as maps. Some regional LGAs had a small number of hospitalisations and were associated with very few sport/leisure participants.

Hospitalisation rates may be unstable in LGAs with few sport/leisure hospitalisations (Schuurman, Hameed, Fiedler, Bell & Simons, 2008). Hence, to stabilise rates, a smoothing technique was used. The aim was to choose the smoothing method that produced estimates similar to the rates of the underlying areas, as some spatial units of the analysis were larger than others (Devine, Louis & Halloran, 1994). Therefore, the sport/leisure injury hospitalisation rates were stabilised using the EB method.

Although this thesis has demonstrated a higher incidence of sport/leisure injuries in rural or regional areas, it has also demonstrated the variation in sport/leisure injury hospitalisation rates within regional LGAs in Victoria. The south-west regional of Victoria (south-west region) has very high incidence rates compared to other Victorian LGAs. Chapter 5 presented a series of maps to describe this spatial pattern by the selected categories of demographic characteristics and specific sports. Interestingly, the observed spatial pattern of LGAs with higher incidence rates was different across age groups and sporting activities, indicating the target areas for injury prevention efforts need to be different based on demographic characteristics and specific sports. For example, there was a higher incidence of Australian Football injury hospitalisations in western regional LGAs in Victoria but the incidence of soccer injury hospitalisation was higher in metropolitan LGAs.

The thesis has shown that maps are useful for describing spatial patterns; patterns can be analysed through visual inspection. However, visual inspection is not sufficient to test the null hypothesis that these sport/leisure injury hospitalisation rates are randomly distributed across Victoria. Therefore, Chapter 6 tested this null hypothesis by calculating spatial cluster statistics. The spatial cluster statistic quantifies a relevant aspect of a spatial pattern (Wilson & Fotheringham, 2008) and an analysis of clusters of overall and selected activity-specific injury hospitalisations was conducted. The spatial pattern of the entire study area was summarised using the Moran's *I* method because several tests identified this as a powerful

test for continuous data (compared to other tests such as Geary's c) (Moore & Carpenter, 1999). The results obtained from Moran's I statistic using the 8-nearest neighbours as the conceptualisation of spatial relationship showed evidence of spatial autocorrelation or spatial clustering in overall and selected activity-specific injury hospitalisations rates. However, the intensity of clustering as indicated by Moran's I varied across different sporting activities.

The application of Getis Ord-Gi* demonstrated that the location of observed clusters of high and low incidence rates were different for overall and activity-specific incidence rates. The clusters of high and low rates of sport/leisure injury hospitalisations were in south-western regional and metropolitan Victoria respectively. Sport/leisure injury hospitalisation clusters were at the same location as Australian football injury hospitalisation clusters. This indicates that the pattern of overall sport/leisure injury hospitalisations was influenced by the Australian football hospitalisations in Victoria. The highest and lowest rates of soccer and basketball injury hospitalisations were observed in metropolitan LGAs and regional LGAs respectively. The high and low rates of cricket injury hospitalisations were clustered in regional LGAs of south-west and north-east Victoria.

The reason for the observed pattern of high and low rate clusters identified in this thesis is unclear, but it may be due to the availability of safe sport/leisure facilities and the diversity of people living in those areas. For example, Australian Football is popular among Victorians and is the leading sport for injury hospitalisation, especially in regional LGAs compared to metropolitan LGAs. Further, the largest proportion of injuries occurred at sport and athletic areas. Chapter 6 addressed the fundamental geographic questions of 'Where are the areas with high and low injury hospitalisation rates?' The next question to address is 'what factors influenced that observed pattern?' To address this, the neighbourhood characteristics that may have been influenced that pattern were identified. The specific characteristics considered important were from broad categories of diversity, social engagement, economic and education neighbourhood characteristics.

The correlations between selected neighbourhood characteristics and overall and activity-specific sport/leisure injury hospitalisation rates showed that not all the selected variables are significantly associated with all type of sports. The relationship between overall sport/leisure injury hospitalisation and activity-specific rates and significantly associated selected neighbourhood characteristics were investigated using OLS and GWR methods. This thesis has demonstrated that the GWR model performed better than the OLS models comparing the

R^2 and $AICc$ values. This is likely due to the spatial autocorrelation exhibited within the overall and activity-specific injury hospitalisation rates. Similarly, other studies that have applied GWR to model traffic crashes and drownings have previously demonstrated that the GWR performed better than OLS when the injury occurrences are spatially dependent (Dai et al., 2013; Zhang et al., 2015). The results of GWR suggest that the nature of association varies in space between explanatory variables and dependent variables. Importantly, the spatial pattern of association of each model was different than others, suggesting that the explanatory variables are associated with each sport differently in each location. As such, sport/leisure injury prevention strategies might need to be customised based on the associated neighbourhood characteristics in different geographic locations.

There is evidence that web-based applications for the mapping and reporting of epidemiological information increase the uptake and use of spatial information (Jardine et al., 2014). In recent years, there has been increased interest for developing web-based applications for disseminating epidemiological information to broad audiences. Given the availability of open-source web-based technologies and georeferenced datasets, it is now possible to develop cost-effective web-based applications. Therefore, the VASLI was developed using open-source technologies (Python, PostGIS, Leaflet) to disseminate sport/leisure epidemiological information in Victoria. The current version of VASLI can generate information presented in Chapters 4 and 5.

9.3 Limitations of the Research

Some limitations may have affected the conclusions of this study. Therefore, caution is required when interpreting the results. The main aim of this thesis was to investigate the spatial pattern of sport and leisure injuries, not to report injury rates.

Although the hospital admission data were comprehensive, from all public and private hospitals across Victoria, the findings are subject to inherent limitations associated with such databases. The data and analysis were based on the place of residence of the injured person but the injury could have occurred at a different location with unique SES, social or environmental conditions. Moreover, the spatial epidemiological investigation was based on LGAs, even though they do not represent homogenous areas from a geographical perspective. It would have been preferable to use a smaller geographical scale such as postcode, Statistical

Area Level 1 and Statistical Area Level 2, but the injury hospitalisation data and neighbourhood characteristics data is very limited at these levels.

The accuracy of the external cause and activity codes used to identify relevant cases is an important consideration for the validity of hospital admission data. The sport/leisure injury data were extracted from hospital admission data based on sport/leisure activity codes. The accuracy of the activity code data is dependent on the quality of the administrative coding and the information provided at the time of reporting. The activity code can be miscoded or missing if the collected injury-related information in the hospital does not have sufficient detail about the activity that a person was involved when the injury occurred. Previous studies have been identified that a substantial proportion of sport injury cases in hospital admission data either been coded as “unspecified activity” or a missing code (Finch & Boufous, 2008; Soo, Lam, Rust, & Madden, 2009). With this evidence, there is a possibility of under-reporting of sport/leisure injury hospitalisations in the data used in this PhD thesis. Additionally, the injury data were also analysed in this thesis based on other external cause codes that would also depend on the quality of the administrative coding and provided injury-related information in the hospital. Therefore, there is a possibility of missing or miscoding of external cause codes leading to over- or under-reporting of the total number of sport/leisure injury hospitalisations for each category of external cause codes. Finally, it is important to recognise that dataset excluded Victorian residents treated outside of Victoria.

Due to a significant change in Victorian hospital admission policy in July 2012 (DHHS, 2012), people were not eligible for hospital admission if the patient received their entire care within a designated ED or urgent care centre. This has reduced the number of admissions recorded on the VAED for the year 2013. For this reason, VISU excluded cases that were treated within the ED before the end of the 2013 financial year, as well as some residual cases after this date. The adjustments may have affected the number of hospitalisations reported by VISU for this thesis.

The epidemiologic summary measures, such as incidence rates, standardised mortality/morbidity ratio and relative risk, are most commonly used in spatial injury epidemiological studies (Singh et al., 2016). The hospitalisation rate or incidence rate was used as a summary measure in this thesis for all analyses. The sport/leisure participation varies by LGA particularly in each sport. However, due to the unavailability of sport/leisure participation data at the LGA level, this study used statewide participation rates to derive the

sport/leisure participation estimates in each LGA. This may have affected the participation-adjusted rates throughout the analysis. The dataset only contains the number of injuries, not the number of injured participants. This limits the calculation of person-based incidence rates because, to more accurately calculate this rate, the number of injured participants would be included in the numerator, but removed from the denominator.

In the current dataset, the geographical location associated with each case is the LGA of the injured person, not the injury location. Therefore, the analysis is limited to area-level analysis. The availability of actual injury location would make it possible to investigate the influence of physical characteristics of injury location such as ground type, intersection and body of water on injury occurrence. The results could be more valid if the injury and neighbourhood characteristics data were available at the smaller geographical scales.

Although there are a number of cluster and ecological analysis methods available, there is a lack of research that provides guidelines to select the appropriate method for the different types of datasets. Therefore, the methods used in the study were selected based on methods considered appropriate in published studies for similar data based on the spatial scale, spatial extent, spatial resolution and spatial intensity. The results may vary if a different method is used for spatial epidemiological investigation of sport/leisure injuries.

As stated earlier, the aim of this thesis was to investigate spatial patterns and demonstrate the importance of spatial epidemiological approaches in sport/leisure injury research. Therefore, the reader should focus on the spatial outputs derived from the spatial epidemiological methodology rather than the numbers associated with those spatial outputs.

9.4 Practical Implications

Prioritising sport/leisure injury prevention requires high-quality evidence on the population consistently at greater risk of injury and factors that increase injury risk (Finch, 2011). An identified research gap in the literature is addressed in this thesis, as it provides high-quality information to enhance the available body of knowledge. The findings are directly relevant to the identification of target population groups and geographic locations for the prevention of sport/leisure injuries in Victoria, Australia.

This thesis has demonstrated that sport/leisure injuries vary by geographical location in Victoria. Moreover, these spatial patterns differ by age group and sport. The mapping of

sport/leisure injuries by age group and specific sport identified priority LGAs for the prevention of sport/leisure injuries. Using a rigorous methodological approach, specific spatial clusters (hot and cold spots) were identified in the distribution of sport/leisure injuries by specific sports. The findings showed evidence of clustering and location within both hot and cold spots. By specific sports, high and low hospitalisation rates clustered differently in specific regions in Victoria. This indicates that the priority injury prevention efforts need to target different locations based on specific sports.

The selected neighbourhood characteristics investigated in relation to sport/leisure injury were also associated differently with each sport; the nature of association also varied by location. This indicates that the influence of neighbourhood characteristics on injury occurrence varies by location. Therefore, there is a need to understand the influence of neighbourhood characteristics in each neighbourhood before interventions are introduced to reduce sport/leisure injuries.

Spatial findings were presented in the form of maps that can be easily understood and interpreted by injury prevention policymakers and key stakeholders. The overall findings provide new insight into the populations that should be targeted for preventive efforts and the nature of associations with selected neighbourhood characteristics when devising and implementing intervention strategies. Despite the earlier identification of sport/leisure injuries as public health issues and the implementation of prevention strategies, there has been a significant increase in sport/leisure injury hospitalisations in recent years (Finch et al., 2015; Finch et al., 2013). The findings of this thesis will make it possible to optimise the effect of prevention strategies by targeting high-risk populations. The VASLI has the potential to inform planning sport/leisure injury prevention strategies and increase awareness of the utility of spatial information for all stakeholder groups.

9.5 Future Research Directions

Despite the limitations described in section 9.3, this research has demonstrated that the spatial epidemiological approach is important to address epidemiological questions from a geographical perspective. This thesis limited its investigation to the LGA level because of limited availability of data at a smaller geographic scale. However, injury and determinant data are increasingly becoming available at finer geospatial resolution. Future research should

consider a smaller geographical unit for analysis and the geographic variation of participation for deriving reliable estimates of participation-adjusted incidence rates.

Injury location is an important attribute for the spatial epidemiological investigation, which is not captured in current data collection systems. Therefore, future research should investigate data collection methods that can also capture injury location so the impact of the geospatial location of the injury-causing event, not just the injured person's place of residence, can be assessed.

Using a selection of neighbourhood characteristics, this thesis has sought to explain why some geographical areas have a higher rate of hospitalisations than others. To further explain the patterns observed, future research needs to examine other factors, such as physical environment, environmental and sports delivery factors in the areas with high and low incidence rates.

The web-GIS tool developed in this thesis constitutes the first phase in the development of a full analytical web-GIS platform for spatial epidemiological investigation of sport/leisure injury data. There are several issues remaining that need to be addressed in future work related to the web-GIS tool including usability, privacy and security settings. These topics were outside the PhD research with the tool currently presented only as a proof in concept. The web-GIS tool constitutes the first phase in the development of a full analytical web-GIS platform for spatial epidemiological investigation of sport/leisure injury data.

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Appendix 1: Search Strategy for Inclusion of Papers to Review

Search terms

#1 - Geographic variation, geographical variation, geographic distribution, geographical distribution, geographic analysis, geographic analyses, spatial clustering, spatial cluster, spatial interaction, spatial autocorrelation, spatial auto-correlation, geographical mapping, spatial analysis, spatial analyses, spatial heterogeneity, geographically weighted, hot spot, hot-spot, high risk, hot spots, hot-spots, geographic information systems, geographic information system, GIS, spatial error modelling, geospatial, geo-spatial, exploratory data analysis, spatial correlation, spatial Bayesian modelling, geographical risk factors, spatial externality, geographical characteristics, conditional autoregressive, geographical inequalities, spatial aggregation, spatiotemporal, spatio-temporal, spatial temporal, neighbourhood, spatial structure

#2 - Trauma, traumas, traumatic, injury, injuries, injured, drown, drowning, drowned, burn, burns, fall, falls, crash, crashes, accident, accidents

#3 - Violent, violence, war, suicides, gene, genes, genital, genetic, rat, cell, soil, DNA, cancer, biological, gait, animal

Search strategy

(#1 AND #2) NOT #3

Databases

Medline, Academic Search Complete, CINAHL Complete, Engineering Source, GeoRef, Health Source: Nursing/Academic Edition, PsycINFO, SPORT Discus with Full Text, Web of Science

Eligibility criteria

Inclusion criteria

- Unintentional injuries
- Spatial injury epidemiological studies
- Population level studies
- 2000-2015 inclusive
- Only original data studies were included

Exclusion criteria

- Crash, collision and accident data
- Suicides or social harm related deaths or injuries

Appendix 2: Characteristics of Included Studies

Reference	Study area/ injury data source (year)	Injury cause	Mapped variables	Map type	Clustering	Cluster detection	Geographical correlation methods	GIS packages	Smoothing
(Towne et al. 2015)	Texas Hospital Inpatient Discharge Public UseData File (2007- 2011)	F	IR	CM	-	-	-	ArcGIS	-
(Stylianou et al. 2015)	England and Wales international Burn Injury Database (iBID) (2003-2011)	B	IR	CM	-	-	-	STATA	-
(Shenoi et al. 2015)	Harris County, Texas Houston Fire Department and county fatality records (2003-2007)	D	FM	DM	NnH, Moran's I	-	CAR	CrimeStat, ArcGIS	-
(Nunn and Newby 2015)	Indiana Indiana State Police Automated Reporting Information Exchange System (ARIES) (2003-2011)	R	FM,IR	DM/CM	NNI, Moran's I	LISA	-	STATA, ArcGIS	-
(Mohan et al. 2015)	Vellore, India District Police Superintendent's office (Jan 2005-May 2007)	R	FM	CSM	-	-	-	ArcGIS	-
(Lawrence et al. 2015)	Melbourne State of Victoria's road authority (VicRoads) (2000-2011)	R	-	-	Moran's I	KDE	-	ArcGIS	-
(Bamzar and Ceccato 2015)	Sweden Swedish National Board of Health and Welfare (2001-2010)	F	IR	CM	-	-	-	-	-
(Heng et al. 2015)	London International Burn Injury Database (iBID) (2007-2013)	B	RR	CM	Moran's I	-	-	R	BYM

(Forst et al. 2015)	Illinois State of Illinois trauma registry (ITR) (2000-2009)	O	FM	CM	Moran's I ,	SaTScan	-	SaTScan	-
(DiMaggio 2015)	New York New York City Department of Transportation (2001-2010)	R	RR	CM	-	-	-	R	BYM
(Slaughter et al. 2014)	New York Bellevue Hospital, trauma center in New York City (Dec 2000-Jun 2011)	R	FM	DM	-	KDE, Getis ord statistics	-	Maptitude, ArcGIS	-
(Raghavan et al. 2014)	Manitoba, Canada Population Health Research Data Repository, Manitoba Centre for Health Policy, University of Manitoba (1984-2006)	Dog-bite	IR	CM	-	-	-	SAS	-
(Mian et al. 2014)	Georgia and South Carolina National Trauma Registry of the American College of Surgeons data set (2006–2009)	B	IR	CM	-	-	-	ArcGIS	-
(Goltsman et al. 2014)	New South Wales New South Wales Severe Burns Injury Service (2006-2010)	B	RR	CM	Moran's I	Getis ord statistics	-	ArcGIS	-
(Hosking et al. 2013)	Auckland New Zealand National Minimum Data Set (2000-2008)	R	IR	CM	-	-	-	ArcGIS	-
(Harlan et al. 2013)	Maricopa, Arizona Maricopa County Department of Public Health (2000-2008)	B	FM	CSM	-	-	-	-	-
(Dai et al. 2013)	Georgia Child Advocate in Georgia (2002-2008)	D	IR	CM	-	KDE, LISA	GWR	ArcGIS	-
(Unni et al. 2012)	Middle Tennessee Trauma registry, pediatric trauma center (2007-2009)	R	IR	CM	-	-	-	ArcGIS	-

(Sharif et al. 2012)	Texas Storm Data publication (1959-2009)	D	FM	CM	-	-	-	-	-
(Poulos et al. 2012)	New South Wales NSW Admitted Patients Data Collection (2000-2005)	R	RR	CM	Moran's I	-	-	MapInfo	BYM
(Morency et al. 2012)	Laval and Montréal Island, Canada Ambulance services (Dec 2008-Jan 2009)	F	FM	CSM	-	-	-	ArcGIS	-
(Huff et al. 2012)	Texas Trauma registry data (2004-2010)	R	IR	CM	-	-	-	ArcGIS	-
(Chan et al. 2012)	WellingtonDufferineGuelph health region, Ontario, Canada Ontario provincial health planning database (2002-2006)	F	RR	CM	-	-	-	WinBUGS, ArcGIS	-
(Nunes and Nascimento 2012)	São Paulo, Brazil Unified Health System (2007-2009)	R	SMR	CM	Moran's I	LISA	-	Terraview	-
(Statter et al. 2011)	Service area of the Hospital, Chicago University of Chicago Medical Center pediatric trauma center (2002-2009)	R	FM	DM	-	Getis ord statistics	-	-	-
(Spoerri et al. 2011)	Switzerland RTA mortality records (2000–2005)	R	SMR	CM	-	-	-	WinBUGS, STATA	Poisson regression model
(Silva et al. 2011)	Pernambuco, Northeastern Brazil State of Pernambuco (2000-2005)	R	IR	CM	Moran's I	-	-	TerraView	Empirical Bayes model
(Razzak et al. 2011)	Karachi medico-legal office (Jan 2004-Dec 2004)	R	FM	DM	-	-	-	ArcGIS	-
(Lateef 2011)	Karachi Major trauma centres (2008)	R	FM	DM	-	-	-	-	-

(Lai et al. 2011)	Hongkong Kwong Wah Hospital (2006–2007)	F	FM	DM	NnH	KDE	-	-	-
(Nagata et al. 2011)	Hanoi Hanoi city police agency (Jan 2006-Dec 2006)	R	FM	DM	-	KDE	-	ArcGIS	-
(Cinnamon et al. 2011)	British Columbia, Canada Insurance Corporation of British Columbia's pedestrian injury dataset (2000-2005)	R	-	-	-	KDE	-	ArcGIS	-
(Edelman et al. 2010)	Utah State databases (1997-2001)	B	RR	CM	-	-	-	ArcGIS	-
(Dey et al. 2010)	United states of America Centers for Disease Control and Prevention BioSense system (Nov 2007-Mar 2008)	F	-	-	-	Spatial scan statistics	-	SaTScan	-
(Chakravarthy et al. 2010)	California California Statewide Integrated Traffic Record Systems (2000-2004)	R	FM	DM	-	-	-	ArcGIS	-
(Weiner and Tepas 2009)	Jacksonville, Florida ED and trauma registry data (2002-2006)	R	FM	DM	-	KDE	-	ArcGIS	-
(Turner et al. 2009)	New South Wales NSW Inpatient Statistics Collection (Jul 1998-Jun 2004)	F	RR	CM	-	-	-	-	Bayesian model
(Sukhai et al. 2009)	South Africa National Department of Transport (NDoT) (2002-2006)	R	IR	CM	-	-	-	Arc GIS	-
(Schuurman et al. 2009)	British Columbia, Canada Insurance Corporation of British Columbia and BCTR (2000 to 2005)	R	-	-	-	KDE	-	ArcGIS	-

(Lai Martin et al. 2009)	Mong Kok, Hong Kong Telephone interview of patients attending Kwong Wah Hospital as a result of fall, (July 2006-Sept 2006, Jan 2007-Dec 2007)	F	FM	DM	NnH	KDE	-	ArcGIS	-
(Maples and Tiefenbacher 2009)	Texas National Climatic Data Center Storm Events database, Spatial Hazard Events and Losses Database for the United States database (1950-2004)	D	FM	CM	-	-	-	-	-
(Lai Low et al. 2009)	Mong Kok, Hong Kong Telephone interview of patients attending Kwong Wah Hospital as a result of fall, (July 2006-Sept 2006, Jan 2007-Dec 2007)	F	FM	DM	NnH	-	-	CrimeStat	-
(Erdogan 2009)	Turkey Police and gendarmerie reports (2001-2006)	R	IR	CM	Moran's I,	Garey c, LISA, Getis ord statistics	GWR	ArcGIS, GeoDa, CrimeStat	Empirical Bayes model
(Dissanayake et al. 2009)	Newcastle, England Tyne and Wear Traffic Accident and Data Unit (2000-2005)	R	FM	DM	-	-	-	ArcGIS	-
(Jones et al. 2008)	England and Wales Stats19 (1995-2000)	R	FM	CM	Moran's I	-	-	ArcGIS	-
(Hu et al. 2008)	China Transportation and communications yearbook (1986-2006)	R	IR	CM	-	-	-	EpiInfo	-
(Haynes et al. 2008)	New Zealand Crash Analysis System based on highway - police reports and maintained by Land Transport New Zealand (1996-2005)	R	IR	CM	-	-	-	-	-
(Eksler et al. 2008)	25 European Union (EU) National road administration and statistical offices (2002)	R	RR	CM	-	-	-	WinBUGS	Bayesian model

(Eksler and Lassarre 2008)	Belgium Belgian National Statistical Office (2000-2005)	R	RR	CM	-	-		WinBUGS	Bayesian model
(de Pina et al. 2008)	Portugal National Hospital Discharge Register (2000-2002)	F	IR	CM	Moran's I	LISA	-	-	Empirical Bayes model
(La Torre et al. 2007)	Italy Statistics of crash accidents Year 2001 (1999-2001)	R	IR	CM	-	-	-	-	-
(Breslin et al. 2007)	Ontario Ontario Workplace Safety and Insurance Board (2000)	O	IR	CM	-	-	-	-	-
(Yan-Hong et al. 2006)	Shanghai Traffic Administration Bureau, Shanghai's 494 hospitals (1987-2003)	R	IR	CM	-	-	-	ArcGIS	-
(Paulozzi 2006)	United States of America Centers for Disease Control and Prevention's Web-based Injury Statistics Query and Reporting System (1999-2002)	R	IR	CM	-	-	-	EpilInfo	-
(Niekerk et al. 2006)	Cape Town Red Cross Children's Hospital register (Jan 1999 - Dec 2000)	B	IR	CM	-	-	-	-	-
(Morency and Cloutier 2006)	Montreal, Canada Ambulance services information systems (1999-2003)	R	FM	DM/CM	KDE	-	-	ArcGIS	-
(Fouillet et al. 2006)	Paris Centre d'Epidémiologie sur les Causes médicales de décès (Cépi-Dc) of INSERM (2000-2003)	B	SMR	CM	-	-	-	-	-
(Lassarre and Thomas 2005)	Europe The international road traffic accident database (1998)	R	SMR	CM	Moran's I, Garey C	-	-	-	Emprical Bayes model

(Haynes et al. 2005)	England and Wales Stats 19 (1995–1999)	R	SMR	CM	-	-	-	-	-
(Durkin et al. 2005)	Wisconsin Wisconsin Crash Outcome Data Evaluation System (CODES) (1992-2001)	R	IR	CM	-	-	-	ArcGIS	-
(Nkhoma et al. 2004)	Texas Centers for Disease Control and Prevention (1980-2001)	P	-	-	-	Spatial scan statistics	-	SaTScan	-
(Yiannakoulis et al. 2003)	Alberta Administrative health data systems, Alberta Health and Wellness (1997–98)	F	IR	CM	-	Spatial scan statistics	-	SaTScan	Empirical Bayes model
(Williams et al. 2003)	St. Louis Two Children hospital (1995)	B	IR/RR	CM	-	-	-	ArcGIS, WinBUGS	Bayesian models
(Hijar et al. 2003)	Mexico Death certificates (1994-1997)	R	SMR	CM	-	-	-	MapInfo	-
(Grabowski et al. 2002a)	United States of America, NTSB factual reports (1983-1998)	Av	IR	CM	-	-	-	ArcGIS	-
(Grabowski et al. 2002b)	United States of America NTSB factual reports (1983-1998)	Av	IR	CM	-	-	-	ArcGIS	-
(Peek-Asa et al. 2000)	Los Angeles County Coroner's Office/hospitals in Los Angeles County (1994)	ND	FM/IR	DM/CM	-	-	-	ArcGIS	-

F = Fall , B = Burn, R = Road traffic, D = Drowning, O = Occupational or work-related, P = Poisoning, ND = Natural disasters, Av = Aviation-related, IR = incidence rate, RR = Relative risk, SMR = Standardised mortality ratio, FM = Frequency, DM = Dot maps, CM = Choropleth Maps, CSM = Classed symbol maps, GWR = Geographically weighted regression, BYM = Besag-York-Mollié, NNI = Nearest neighbour index, NnH = Nearest neighbour hierarchical, KDE = Kernel density estimation, LISA = Local indicator of spatial autocorrelation, CAR = Conditional auto-regressive

Appendix 3: Ethics Approval

Approval

Human Research Ethics Committee



Principal Researcher:	Caroline Finch
Other/Student Researcher/s:	Helen Thompson Lauren Fortington Rochelle Eime Himalaya Singh
School/Section:	ACRISP
Project Number:	C15-008
Project Title:	Geographic and epidemiological analysis of sports and recreational injuries of Victoria, Australia
For the period:	25/6/2015 to 31/12/2017

Quote the Project No. in all correspondence regarding this application.

Please note: Ethics Approval is contingent upon the submission of a **Final Project Report** at the completion/discontinuation of the project. **Annual Project Reports** must also be submitted if the duration of the project exceeds twelve months. It is the responsibility of researchers to take note of the following dates and submit these reports in a timely manner, as reminders may not be sent out. Failure to submit reports will result in your ethics approval lapsing.

REPORTS TO HREC:

An annual report for this project must be submitted to the Ethics Officer on:

25/06/2016

28/06/2017

A final report for this project must be submitted to the Ethics Officer on:

30/01/2018

These report forms can be found at:

<http://federation.edu.au/research-and-innovation/research-support/ethics/human-ethics/human-ethics3>

A handwritten signature in black ink, appearing to read "Irene Hall".

Irene Hall

Ethics Officer

2 January 2018

Please see attached 'Conditions of Approval'.

Appendix 4: Ethics Amendment Approval

Amendment Approval
Human Research Ethics Committee



Principal Researcher:	Caroline Finch
Other/Student Researcher/s:	Helen Thompson Lauren Fortington Rochelle Eime Himalaya Singh
School/Section:	ACRISP
Project Number:	C15-008
Project Title:	Geographic and epidemiological analysis of sports and recreational injuries of Victoria, Australia.
For the period:	21/04/2017 to 31/12/2018

Quote the Project No. C15-008 in all correspondence regarding this application.

Amendment Detail: A new data request will be made to VISU to request a dataset with all cell counts available, including those that contain count of less than five.

Extension: 31 December 2018

Personnel: N/A

Please note: Ongoing ethics approval is contingent upon adherence to the Standard Conditions of Approval on Page 2 of this notification.

COMPLIANCE REPORTING TO HREC:

Annual report/s due:

28 June 2017

28 June 2018

Final report due:

31 January 2019

The combined Annual/Final report template can be found at:

<http://federation.edu.au/research-and-innovation/research-support/ethics/human-ethics/human-ethics3>

A handwritten signature in black ink, appearing to read "Fiona Koop".

Fiona Koop
Ethics Officer
21 April 2017

Please note the standard conditions of approval on Page 2:

CRCOS Provider No. 001830

V 2017

Page 1 of 2

STANDARD CONDITIONS OF APPROVAL

1. Conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal required by the HREC.
2. Advise (email: research.ethics@federation.edu.au) immediately of any complaints or other issues in relation to the project which may warrant review of the ethical approval of the project.
3. Where approval has been given subject to the submission of copies of documents such as letters of support or approvals from third parties, these are to be provided to the Ethics Office prior to research commencing at each relevant location.
4. Make submission for approval of amendments to the approved project before implementing such changes. A combined Amendment request template is available for the following:
 - Request for Amendments
 - Request for Extension. Note: Extensions cannot be granted retrospectively.
 - Changes to Personnel
5. Annual Progress reports on the anniversary of the approval date and a Final report within a month of completion of the project are to be submitted to the Ethics Officer by the due date each year for the project to have continuing approval.
6. If, for any reason, the project does not proceed or is discontinued, advise the committee by completing a Final report form.
7. Notify the Ethics Office of any changes in contact details including address, phone number and email address for any member of the research team.
8. The HREC may conduct random audits and / or require additional reports concerning the research project.

Failure to comply with the *National Statement on Ethical Conduct in Human Research* (2007) and with the conditions of approval can result in suspension or withdrawal of approval.